3P-SAMPLING AND ITS POTENTIAL FOR FOREST INVENTORY IN PAKISTAN

by

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STATEMENT

Except where otherwise acknowledged, to the best of my knowledge, the work described in this substantial essay is original and has not been submitted for any degree or diploma in any University.

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ABSTRACT

3P-sampling, the latest evolutionary step in the development of forest sampling designs, is a most efficient design for providing forest resource information so vital to national resource planning.

In this study, the potential of 3P-sampling for forest inventory in Pakistan is investigated. Firstly, the physiography of the country and the nature and role of its forests are described and then the current status of forest inventory is reviewed. It is concluded that more efficient sampling designs and modern technological aids need to be utilised to improve the extent and quality of information on the natural forest resource.

Essential literature on 3P-sampling is then reviewed and case studies demonstrating particular applications of the technique in A.C.T. forest are described.

The author concludes that 3P-sampling has undoubted potential for inventorying the forests of Pakistan. The technique can be used either alone or in combination with other sampling schemes to improve the efficiency and accuracy of estimation. It could be applied immediately in Pakistan for marking compartments for sale of forest produce, inventorying large tracts of timber prior to preparing management or development plans and for log-scaling. It also has application in reforestation, reclamation works and wildlife and range management.

CHAPTER 1

INTRODUCTION

1.1 NATURE OF THE PROBLEM

Forests occupy a unique position among natural resources. They not only provide essential products for human welfare, such as wood for industry, and fuelwood and timber for domestic use, but they also afford protection to other resources such as soil, water and wildlife. The way the forest resource and other natural resources are used, largely determines the physical well-being of the people of a country. Abuse or neglect of the soil and reckless destruction of the forests have led to the downfall and sometimes the extinction of a number of civilizations, whereas proper use of these resources has made it possible to achieve regular benefits over a long period of time.

Rapidly increasing populations and improved standards of living have increased tremendously the consumption of wood and other forest products in many countries of the world. This has resulted in a heavier drain on the forests. On the other hand, protection and care of the forests which clothe the hills and mountains is necessary to maintain the productivity of agricultural pursuits on the plains. These pursuits are vital for the continued existence of mankind.

To maximize benefits from forests, in terms of wood and other products for local consumption, and to insure constant supply of raw materials for industry, which aids socio-economic development, better and more intensive management of the forests resource is required. This cannot be achieved without reliable inventory data which are the basis of sound management decisions whether at the local, regional or national level. Especially is this so with forest resources which normally cover vast areas of diverse topography. Detailed information on the resource, viz. its kind, ownership, areal extent, quantity and quality is needed. However, time, cost, accessibility and the size of the resource make it impossible to inventory all areas through 100 percent enumeration. Sampling is usually necessary.

The objective of sampling is to obtain a reliable estimate at the lowest possible cost. A variety of sampling techniques has been developed. The technique to use in a given situation is determined by a number of factors, including the purpose of the measurement, precision of estimate desired, cost, accessibility, value of the resource and labour. Choice of the proper sampling technique for a given objective and set of conditions is essential for efficient inventory.

1.2 SCOPE OF THE STUDY

In recent years intensive work has been done on a new sampling technique, based on variable probability sampling, called "3P-sampling".[1] As discussed later in Chapter 4, this method of sampling has advantages in terms of precision, time and cost, and it has wide application in forest inventory. It has attracted much attention throughout the world but very little in Pakistan. Tariq (1974) described the basic technique and Hussain (1974) gave one example of its use in a coniferous forest in Pakistan.

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1 3P-sampling: A sampling method introduced by L.R. Grosenbaugh (1964), Selection of the sample tree is based on the concept that the probability of selection of a tree is proportional to a prediction of its volume. In other words, the larger a tree, the more chance it has of being selected in the sample.

The study commences with an examination of the physiography and forests of Pakistan, and a review of the current status of forest inventory in the country. The concept of 3P-sampling and its application in forest inventory is then examined. Three case studies using the technique in the exotic pine forests of the Australian Capital Territory are described. Finally, the potential of a 3P-sampling for forest inventory in Pakistan is discussed.

1.3 NEED AND IMPORTANCE OF THE STUDY

Pakistan has about 3.7% of its total land area under forests. This is insufficient to meet not only the ever increasing consumption of wood and other forest products but also the increasingly recognised "welfare functions" (Ayaz, 1975) of the forest. A rapidly increasing population in Pakistan has resulted in a substantial increase in the import bill for wood and its products. This situation can be eased somewhat by expanding the area under forest through plantation establishment but the availability of suitable land for this purpose is limited. The only other alternative is to maximize benefits from the existing resource through better management techniques. Khan (1967) points out that the Coniferous forests of Pakistan, a major productive resource in the country, have been managed much too conservatively, largely because of lack of information. This highlights a need for more efficient inventory. Phillis (1971) states that because of rapid advances in technology, it is desirable for any country to review and update its inventory procedures periodically. The author of this study attempts to do this by becoming familiar with this modern technique of forest sampling which, hopefully, will have ready application in the forests of Pakistan.

Another inportant factor, which must be considered when updating inventory procedures in Pakistan, is the increasing availability of high speed computers. It is now possible to prepare summaries of inventory data and do mathematical calculations reliably and speedily. Thus it is possible to examine quickly established procedures, test alternatives and adopt new techniques which previously would have been impracticable. With rapid technological development, the use of computers is becoming cheaper each year and consideration must be given to their use in processing the results of forest inventories in Pakistan.

1.4 OBJECTIVE OF THE STUDY

The primary objective of this study is to assess the potential of 3P-sampling for improving the efficiency of forest inventory in Pakistan.

CHAPTER 2

PHYSIOGRAPHY AND FORESTS OF PAKISTAN

2.1 PHYSICAL FEATURES AND CLIMATE

Pakistan possesses a land resource of 87 816 million hectares. This includes Azad Kashmir and the Northern Areas, extending over a wide range of geo-climatic zones. In broad outlines, the country consists of the flat Indus Valley, (Fig 2.1), the northern part of which is covered by outcrops of low hills of the Siwalik range. This outcrop area has been badly eroded and is now reduced to a labyrinth of ravines. In the middle of this zone near Sukkur, outcrops of limestones occur and in the southern part, near the coast, outcrops of sandstone are found. The soils here vary from clay to pure sand, large stretches of which are saline and water logged. In general the underground water is very deep. Salt range consisting of massive rock salt lie in the north central zone.

The Kohi-sulaiman (Sulaiman) and Kohi-Sultan (Sultan) Ranges form the western part of the Indus Valley, whereas the Kirthar Range extends to the extreme south. These ranges are formed of sedimentary rocks consisting of massive limestone with outcrops of shale, conglomerate and calcite. This southern area of the country consists of broad valleys with gentle and moderately steep slopes, but steep to precipitous slopes occur near the ridges.

The Himalayas border the Indus Valley on the north and north-western side. In the north, the Karakoram Range of the Himalayas form the greatest concentration of high peaks in the world. The lower slopes and hills, consisting of steeply tilted sandstones and arenaceous

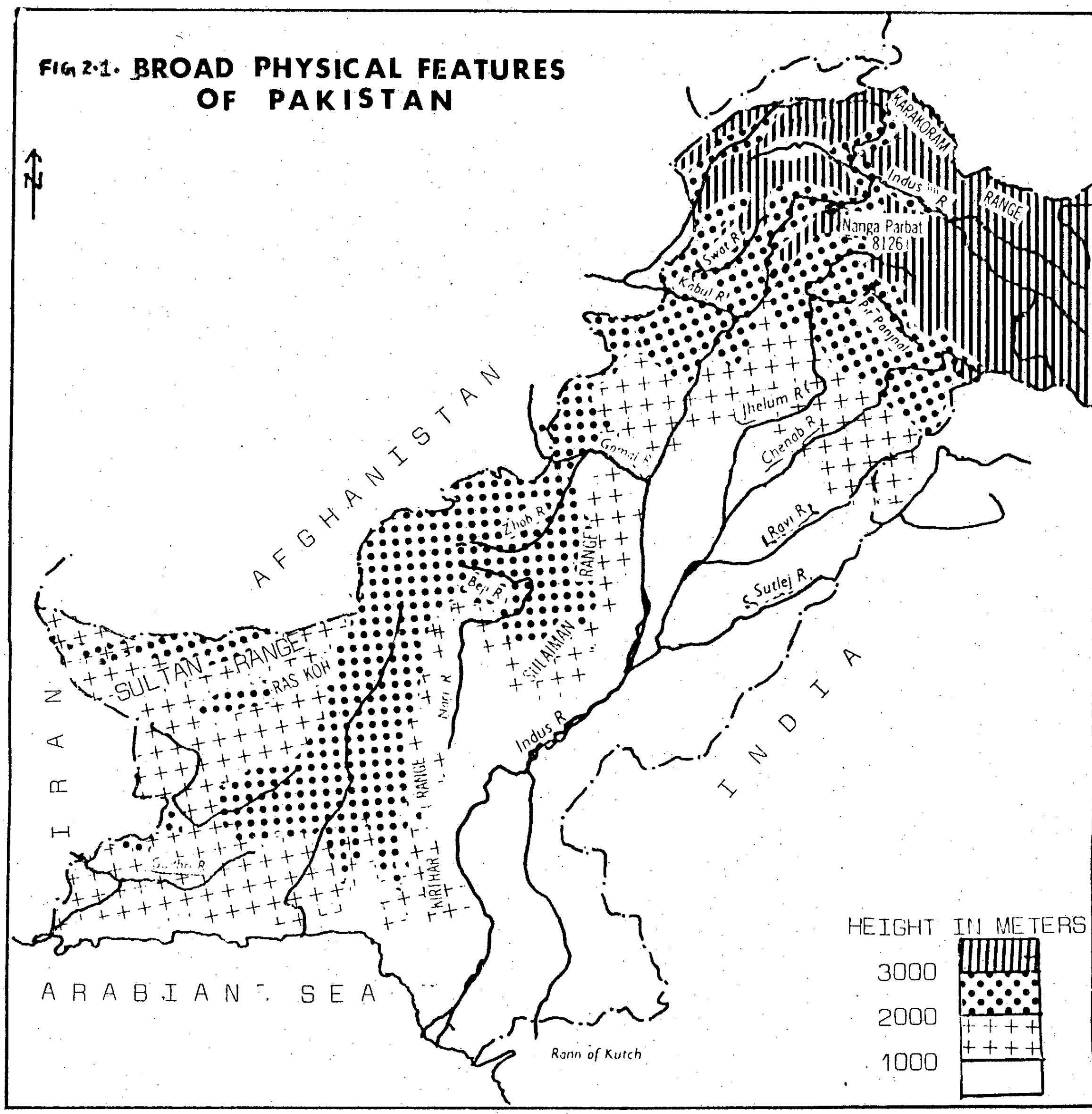

FIG 2.1. BROAD PHYSICAL FEATURES OF PAKISTAN

clay with occasional beds of porous limestone, belong mainly to tertiary formation. The outcrops of sandstone form escarpments. The soil of this zone is often an impregnated reddish clay and clayey loam. At higher elevations in the whole area west of the Jhelum River the rock consists mainly of metamarphic sills of gneissose granite producing, a deep loose soil. Mica, schists and quartzites, and outcrops of shale and limestones are met frequently, in the upper and lower parts of the region respectively. The soil in this region is sandy and well drained. A common feature of the region is the southwardly directed mountains, glaciers and precipitous screes.

The climate of Pakistan is very varied. The greater part of the country is desert or near desert, made habitable by the presence of rivers which are fed by precipitation trapped in the northern hills. The range of diurnal temperatures and the annual differences in temperature are very large. As a result of the great latitudinal and altitudinal ranges in the region, the seasonal rhythms of climate and its extreme variability from time to time, give diversity to the vegetation (Champion, et al. 1965b).

The greatest part of the country is arid, with mean annual rainfall varying from 5mm, in the southern and western part, i.e. the outer ranges of the Himalayas. The south-west monsoons and Atlanto-Mediterranean western disturbances in July to September and December to March respectively are responsible for the bulk of the rainfall in a large part of the country. As a result of atmospheric instability, tropical storms in the Arabian Sea produce thunderstorms which cause rain mostly in the Indus delta. The lower Indus plains receive rainfall only during the south-west monsoons. The Central and Northern sections of the Indus plains also receive some of their precipitation during winter. Whereas, most of the north-western sections such as Peshawar, Quetta and Kalat receive most of their precipitation during winter. (Champion, *et al*. 1965b).

Mean annual range of temperature, i.e. difference between mean annual temperature of the hottest and coldest months becomes marked with increasing latitude and distance from the sea. It is generally 20°F (11°C) in the coastal area, but as high as 44°F (24°C) in some of western margins and 46.4°F (25.8°C) in the extreme north. June is the hottest month in areas under the influence of the south-west monsoon and July in areas away from the monsoons. The mean annual temperature during this period varies from 63°F(17.2°C) in the northern region to about 100°F (37.8°C) in Sibi in interior Baluchistan. January is the coldest month throughout the country, and during this period, mean annual temperature varies from 54°F (12.2°C) in parts of the plain to 3.8°F (-15.7°C) in areas of Kashmir at about 10 000 feet (3050m) altitude. The drop in temperature above 4000 feet (1220m) results in precipitation in the form of snow (Champion, *et al*. 1965b). The country can be classified into four temperature zones (Table 2.1).

Table 2.1 Temperature zones of Pakistan

Zones	Mean Annual Temperature	Mean January Temperature	Type of Winter
Tropical	$>75^{\circ}$F (23.9°C)	$>60^{\circ}$F (15.6°C)	Mild; no frost
Sub-tropical	$65-75^{\circ}$F ($18.3-23.9^{\circ}$C)	$50-60^{\circ}$F ($10-15.6^{\circ}$C)	Not severe; occasional frost
Temperate (montane)	$50-65^{\circ}$F ($10-18.3^{\circ}$C)	$30-50^{\circ}$F ($-1-10^{\circ}$C)	Pronounced with frost & some snow
Alpine	$<50^{\circ}$F (10°C)	$<30^{\circ}$C (-1°C)	Severe; heavy snow

Source: Champion *et al*. (1965b)

2.2 THE FOREST RESOURCE

2.2.1 Though wide geo-climatic variation has resulted in diversification of forest types and their composition, Pakistan is extremely deficient in forest resources. Against a total area of 87 816 thousand hectares (including Northern Areas and Azad Kashmir), the area under the control of the Forest Departments is only 10 877 thousand hectares, i.e. 11.8% of the total land area. Wooded forests constitute only 4256 thousand hectares (4.8%) of which the productive forest area is only 1.5% of the total land area or 31.3% of the area under the administrative control of the Forest Departments. Forest area statistics compiled in 1978 are given in Table 2.2.

2.2.1 MAJOR FOREST TYPES AND THEIR DISTRIBUTION

Champion *et al.* (1965a,b) classified the forest types of Pakistan into a number of major groups, distribution of which is illustrated in Fig.2.2.

MOIST TROPICAL FORESTS

The only type of moist tropical forests present in Pakistan is tidal forests. These are evergreen, poorly developed forests of varying height and density, associated with wet soils of the Indus delta where rainfall is very low and leaching of the soil is slight. *Avicennia offecinalis* is the only tree species present. Beside a limited local use as firewood, this forest type has little commercial value.

DRY TROPICAL FORESTS

(a) *Tropical dry deciduous forests*: These are open forests of mixed deciduous species, which occur in close proximity to human habitation. The type is not important commercially due to its limited area and the comparatively unimportant species constituting it. The

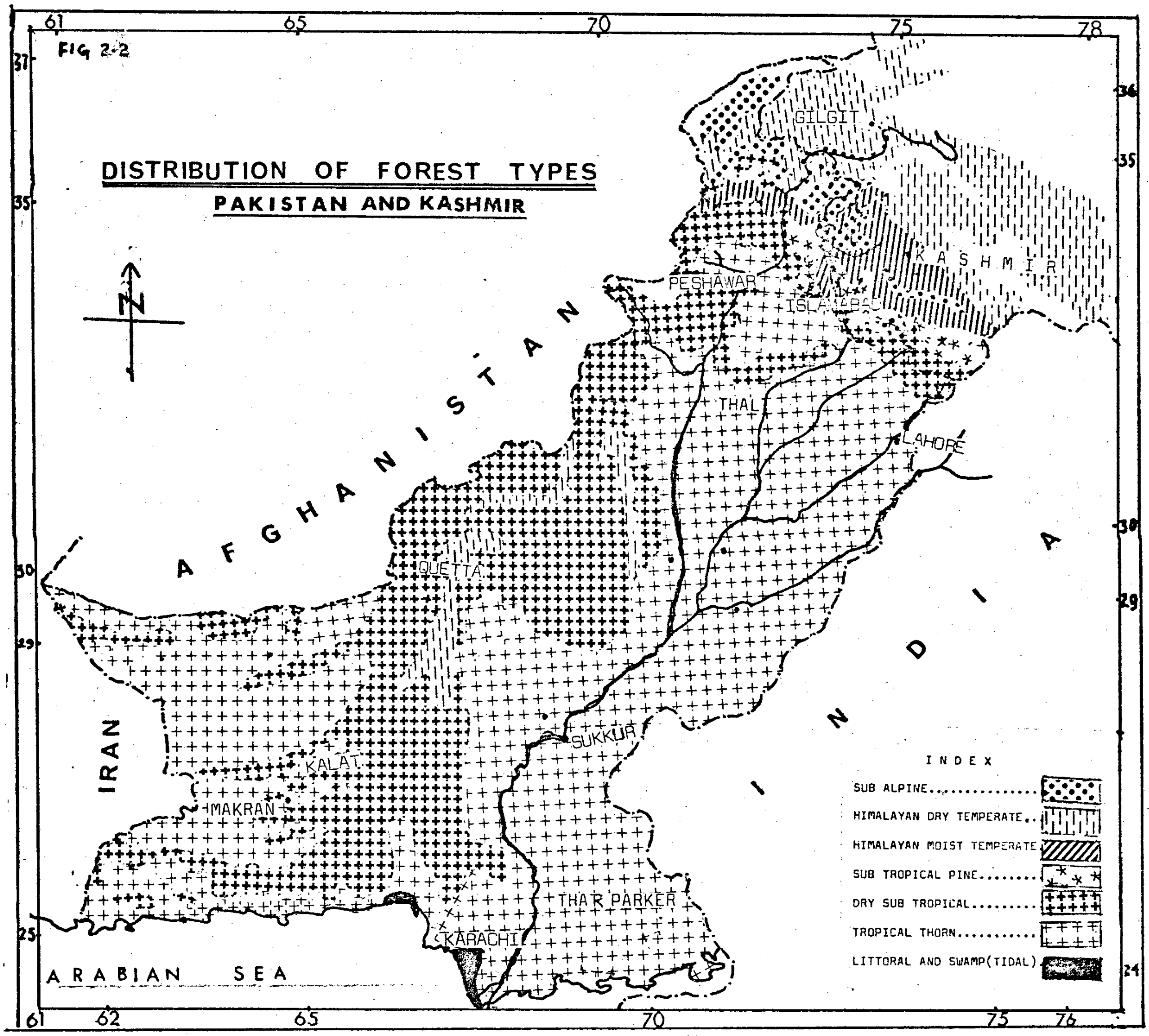
FIG 2-2
DISTRIBUTION OF FOREST TYPES
PAKISTAN AND KASHMIR
N
AFGHANISTAN
IRAN
INDIA
KASHMIR
ARABIAN SEA
GILGIT
PESHAWAR
ISLAMABAD
THAL
LAHORE
QUETTA
KALAT
MAKRAN
SUKKUR
THAR PARKER
KARACHI
INDEX
SUB ALPINE
HIMALAYAN DRY TEMPERATE
HIMALAYAN MOIST TEMPERATE
SUB TROPICAL PINE
DRY SUB TROPICAL
TROPICAL THORN
LITTORAL AND SWAMP(TIDAL)
61
65
70
75
78
62
76
37
36
35
30
29
25
24

Table 2.2 Abstract of area statistics*
(June 1978)

(thousand hectares)

	Total land area[1]	Area under the control of Forest Departments[2]: Area	Area under the control of Forest Departments[2]: % of total land area	Area under the control of Forest Departments minus rangelands: Area	Area under the control of Forest Departments minus rangelands: % of total land area	Production forests[2]: Area	Production forests[2]: % of total land area	Production forests[2]: % of area under the control of Forest Depts: minus rangelands
Provinces	79 610	6 743	8.5	2 931	3.7	942	1.2	32.1
North western Frontier Province	10 174	1 138	11.2	984	9.7	368	3.6	37.4
Punjab	20 627	3 390	16.4	563	2.7	261	1.3	46.4
Sind	14 091	1 125	8.0	668	4.7	313	2.2	46.9
Baluch-istan	24 718	1 090	3.1	716	2.1	-	-	-
Northern Areas	7 042	3 049	43.3	944	13.4	219	3.1	23.3
Azad Kashmir	1 164	582	48.9	380	31.9	169	14.3	44.7
TOTALS	87 816	10 877	11.8	4 256	4.8	1 332	1.5	31.3

* Compiled by Pakistan Forest Institute Peshawar.

1. Total land area figures for North Western Frontier Province, Punjab, Sind, and Baluchistan have been taken from Agricultural Statistics of Pakistan, 1977. For Northern Areas and Azad Kashmir, the figures have been taken from Fifth Five Year Plan.

2. Office records of Provincial Forest Departments.

tree species are Lannea, Sterculia, Flacourtia, Mallotus and Acacia catechu with common shrubs such as Indigofera, Gymnosporia and Adhatoda spp. The type has some local use for providing firewood and grazing for animals.

(b) Tropical thorn forests: This type comprises low open mixed forest of a limited number of xerophytic species. It is the most widespread forest type in Pakistan and occurs in small patches throughout the Indus plains where it has not been brought under cultivation. Main species are Acacia modesta, Euphorbia spp., Prosopis spicigera and Capparis decidua. In saline areas Tamarix spp. and Salvadora oleoides and in degraded saline areas Salsola foetida, Prosopis juliflora and P.glandulosa occur. Development of a thin layer of grass after rain makes this type very important for grazing. In general, commercial value of the forest is low but the type includes two important primary serial sub-types and a large area converted to irrigated plantations.

(i) Tamarix - poplar sub-type: This type occurs along the large rivers in the Indus plains and southern half of the country. The main species are Populus euphratica, Tamarix dioca, Acacia arabica and Dalbergia sissoo. The former two are good light woods and the latter two good heavy woods.

(ii) Inundation babul forest: This is also called 'Riverine forest', which occurs on the banks of the Indus River, especially in its lower tracts. It occurs in strips and its width is determined by the extent of flood water influence, varying from a few hundred meters to 12 kilometers. The main specie is Acacia arabica in more or less pure stands with scattered trees or patches of Populus euphratica, Prosopis spicigera and Tamarix species. Acacia arabica is an excellent wood for mine props, firewood and agricultural implements. Thus this forest sub-type is economically very important. Originally these forests were natural but they are now regenerated by broadcasting seed artificially.

(iii) Irrigated plantations: A considerable area of tropical thorn forests has been converted into irrigated plantations (Khattak, 1976). The chief species being Shesham (Dalbergia sissoo) and Mulbery (Morus alba). The former is an excellent timber for furniture and the latter is used in the manufacture of sporting goods. The growing consumption of industrial wood and the need to develop wood based industries, emphasises the further need to diversify the species to be grown in plantations. Preference being given to fast growing industrial woods such as simal (Salmalia malabricum), Populus spp, Gmelina arborea and Eucalypts spp. etc.

MONTANE SUB-TROPICAL FORESTS

(a) Sub-tropical broad-leaved evergreen forests: This forest type consists of xerophytic, thorny and small leaved, evergreen species. The typical species are Acacia modesta and Olea cuspidata with Dodonea shrub in degraded areas. During the monsoon season there is good growth of herbs and annual grasses on the forest floor. This type occurs in the foot hills of the Himalayas, the Salt range, the Kalachitta range and the Sulaiman range up to a height of 3000 ft (915m). Apart from the supply of firewood to local population and grazing, these forests have no commercial importance.

(b) Sub-tropical pine forests: These are extensive, moderately dense, tall, pure stands of Pinus roxburghii (chir pine). A few scattered, broad-leaved species occur as underwood, of which Quercus incana (oak) is the main specie. The dense undergrowth of thorny species such as Carrissa spinarum, Dodonea viscosa, Myrsine africana and

Berbarus lycium sometimes disappears due to repeated fire. This commercially very important forest type occupies a large area between 3000 ft (915m) to 5500 ft (2676m) in areas of the Western Himalayas which are influenced by the South-West summer monsoon.

TEMPERATE MONTANE FORESTS

(a) Himalayan moist temperate forests: These are tall, moderately dense, coniferous forests with some admixture of broad-leaved trees occuring in patches in shaded canyons. Four coniferous species i.e. Pinus wallichiana (Blue-pine), Cedrus deodara (deodar), Abies pindrow (fir) and Picea smithiana (spruce) occur in almost pure stands depending upon altitude and aspect. Scattered trees of Taxus baccata are also present. The common, broad-leaved species include Quercus spp., Aesculs indica, Juglans regia, Populus ciliata and Prunus specie. Commercially, this is the most important forest type in the W. Himalayas occurring between 5000 ft (1524m) and 10 000 ft (3050m) (except where rainfall is below 40" (1416mm) in the inner ranges), especially in the extreme North-Western parts.

(b) Himalayan dry temperate forests: These are open, evergreen forests comprising coniferous and a few, broad-leaved species. The common coniferous species are Cedrus deodara and Pinus gerardiana (chalgoza pine). In some cases other conifers found in Himalayan moist temprate forest occur in specific microclimates within this forest type. Common broadleaf species are Quercus spp., Pistacia khinjak, Acer spp., and Fraxinus xanthxyloides. This type occurs on the inner ranges of the Himalayas through out their length, beyond the influence of the monsoon. The rainfall, though low, is confined to winter precipitation and spring showers. Altitudinal range is 6000 ft (1829m) to 10 000 ft (3050m). The type which occurs on steep to precipitous slopes is also commercially important.

SUB-ALPINE FORESTS

(a) Sub-alpine forests: These comprise low, open canopy, mixed forests of evergreen coniferous and broad leaf species with deciduous shrubby undergrowth. *Abies spectabilis* is the most common conifer with Blue-pine (*Pinus wallichiana*) occurring on landslips etc. *Betula utilis* and *Rhododendron* are the useful broad leaved species. This type occurs throughout the Himalayas from 11 000 ft (3353m) to the timber limit. As assess improves this type will become commercially important.

(b) Alpine scrub: These are extremely xerophytic alpine forests occurring in the Himalayas from 11 500 ft (3505m) up to the permanent snow line. Scrub formations of 2 ft (0.6m) to 6 ft (1.8m) high comprising of *Salix*, *Lonicera*, *Berberis*, *Juniperus* and occasionally *Rhododendron* are characteristic species. Due to their poor development, these forests are commercially unimportant.

Thus the commercial forests of Pakistan comprise the Coniferous forests, which include sub-tropical pine forests, montane temperate forests and to some extent sub-alpine forests; Irrigated plantations in the tropical thorn forest zone and Inundation babul forests or Riverine forests.

2.2.2 OWNERSHIP OF THE FOREST RESOURCE

Most forests of Pakistan are Government owned. Some are privately owned.

The major part of the State-owned forests is administered by the Forest Organizations. A very small portion is administered by other

Government agencies, such as Municipal Committees or Cantonment Boards, called Municipal Forests and Cantonment Forests respectively. All these types of Government forest are further classified into 'Reserved' forests and 'Protected' forests. 'Reserved' forests are the property of the Government and the local population has no rights and privileges with respect to them, without special authority. In 'Protected' forests the local population have rights and privileges, for grazing, firewood and even free constructional timber. Areas under the administrative control of the Forest Departments may have a third category 'Unclassed' forests which, in due course, will be declared either Reserved or Protected forests (Ayaz, 1975).

The private forests are very small. These may be individually owned forests called 'Guzaras' or forests jointly owned by a village or group of people called 'Communal' forests. Sometimes these forests may be acquired by the Government under special rules for a specified period to stop their further deterioration or to improve conditions (Ayaz, 1975).

2.2.3 IMPORTANCE OF FORESTRY TO THE NATIONAL ECONOMY

Pakistan has only 3.7% of its total land under forest and some 1.5% under reproductive forest. Despite the fact that this percentage is very small, the forest has great socio-economic value. It provides constructional and industrial timber, firewood, grazing, resins and a variety of other minor products to meet the various demands of a large part of the country's population, approximately 81 million people. Table 2.3 summarises the production of timber from the forests of Pakistan (Azad Kashmir and Northern Areas not included) from 1970-71 to 1977-78 inclusive. This production is a source of a large amount of

Table 2.3 Production of timber from forests under control of Forestry Departments of Pakistan

	Thousand Cubic Meter
Year	Total Production
1970-71	292
1971-72	404
1972-73	376
1973-74	359
1974-75	202
1975-76	178
1976-77	221
1977-78	135

Source: Office records of Provincial Forest Departments, Unpublished.

revenue for the national economy. In addition, the indirect benefits of the forests in the form of their "welfare functions" are substantial. The productivity of Pakistan's agriculture plains depends greatly upon the protection of the ground vegetation in the hill country because this regulates the water yeild. Protection to soils, and shelter for wildlife are well recognised functions of the forests of Pakistan. The life span of the country's huge dams greatly depends upon the management of catchment forest.

Although the importance of forests to the national economy, directly or indirectly, is large, Pakistan suffers from a shortage of timber and has to import about 579 thousand m^3 annually. This consumes a large part of the country's precious foreign exchange which is desperately needed for importing other capital goods. Improved management of the nation's forest resources will result in substantial benefits to the country and its people.

CHAPTER 3

CURRENT STATUS OF FOREST INVENTORY IN PAKISTAN

3.1 HISTORICAL BACKGROUND

(a) Pre-partition (pre-1947)

As inventory is the basis of management planning, initiation of forest inventory procedures dates back to the beginning of forest management (Loetsch and Haller, 1964). Until the last quarter of the nineteenth century, forests in the Sub-continent of India were regarded as bounty bestowed upon man by nature. Thus they were treated as a resource to which everyone had free and unlimited access. A growing scarcity of wood began to be felt during the closing period of the last century (1871-1900). This initiated intensive work on forest legislation, demarcation, reservation, settlement and working plan preparation. For the latter, inventory data were collected providing quantitative estimates of the total growing stock and its distribution by species and diameter class, for the purpose of yield regulation. Gradually this work was organized and standardized through a working plan code which provided a broad outline for the organization of field work, method of survey, collection of data and method of compiling the results (Khattak, 1976; Qazi, 1978).

(b) Post-partition (post-1947)

At the time of partition of the Indian Sub-continent, in 1947, 20% of the land was under forests. Pakistan inherited less than one fifth of this (3.7%) of which 5157km^2 only had already been surveyed and inventoried (Qazi, 1978). Despite the urgency of the matter, only 16 362 km^2 had been covered up until 1978. The poor progress is due to a number of factors. Firstly, the infrastructure and organization of the Forestry Department at the time of partition were inadequate. Secondly, forestry was not given due priority in developmental planning and it was kept subordinate to agriculture. Other important factors were the socio-economic problems in forest areas and the constant political instability in the country. In addition the coniferous forests, which are a major part of the forest resource of the country, are mostly inaccessible and cover a large altitudinal range from about 500 meters to 7000 meters above mean sea level. Poor communications and uncertain weather conditions made it very difficult to undertake useful field surveys in a reasonable time and at reasonable cost. Thus, in 1965, a project known as the 'Pre-investment Survey Project for Natural Resource Development' was launched with a view to collect inventory data on the location and extent of commercially exploitable forests including species, composition, size class distribution, growth rate and yield. The project included an area of 51 800 km^2 in the northern part of the country and Azad Kashmir and included 7770 km^2 of unmapped and unattended forest[1] (Khan, 1977; Qazi, 1978). In spite of many difficulties e.g. uncertanity of weather and lack of equipment, good progress has been made in photographing the forests and preparing topographic maps, collecting forest resource information, assessing land suitability and compiling an integrated land resource map (Khan, 1977). Table 3.1 summarises the achievements up to mid-1975.

In addition, encouraging results were obtained in early trials using LANDSAT imagery for mapping and inventory of inaccessible forests in northern part of the country (Khan, 1977). Qazi (1978) points out, however, that in spite of these efforts, so far no systematic effort has

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1 Unattended forests: Forest areas which have not been surveyed and managed previously.

Table 3.1 Status of the pre-investment survey project - 30 June 1975

Particulars	Target (km^2)	Achievements (km^2)	Deficit (km^2)
1. Aerial photography			
(i) 1:50 000 Scale	50 000	42 000	8 000
(ii) 1:20 000 Scale	40 000	19 000	21 000
2. Preparation of maps			
(i) Base map	40 000	39 000	1 000
(ii) Topo maps	50 000	35 000	15 000
(iii) Resource maps	65 000	27 000	38 000
3. Soil Survey	40 000	7 000	33 000
4. Preparation of reports			
(i) Forest inventory	12 500	6 000	6 500
(ii) Land use/ integrated resource survey	65 000	27 000	38 000

Source: Khan, (1977)

been made to compile data of the country's total forest resource, either directly through inventory, or by compilation of data already available in regional management plans and development reports. Information on the wood resource present in areas classed as non-forested, though supporting some trees, is also lacking.

3.2 CURRENT INVENTORY METHODS

Presently two methods of forest inventory are in vogue. Both, directly or indirectly involve sampling.

Angle-count sampling by prism, based on a systematic design, is used to collect data for preparing regional and local forest management plans. Procedures involve placing a systematic grid (random start) over the entire forest and sampling at grid intersection points. The sample taken in this way is considered to be more representative and efficient than one selected by simple random sampling (Qazi, 1978).

An inventory project with two phase sampling is used in the pre-investment survey of the northern parts of the country. In the first phase, a large sample is selected on aerial photographs. All the measurements related to that sample are recorded from the photographic image. In the second phase, ground samples are taken on a subsample of the units of the first phase. The relationship between the field measurements and those taken from the photographic image is computed using linear regression. The ratio so calculated is then used to adjust and extrapolate measurements using the photographic image to estimate data for the whole tract. (Qazi, 1978.)

In all these sampling procedures, sample size (n) is determined using the traditional random sampling formula $n = \frac{cv^2 t^2}{E^2}$ (Qazi, 1978) where:

cv = coefficient of variation

E = sampling error desired

t = students "t" at a given level of probability.

If a topographic map is used within each stratum, a systematic sample with a random start is drawn.

3.3 DATA COLLECTION AND COMPILATION

A specific format is used for collecting data for management plan preparation. All the computation is done by hand calculators and data are further manipulated to compile individual compartment history files. Diameter is recorded in 1 inch (2.5cm) classes and volume is calculated using local volume tables for the species concerned. Annual cut is predicted for the planning period based on the yield calculated from measurements taken from a core sample or read from yield tables. Information gathered from the interpretation of aerial photographs and from ground surveys is recorded using digital codes (Qazi, 1978).

CHAPTER 4

REVIEW OF 3P-SAMPLING

Three-P sampling was conceived by L.R. Grosenbaugh (1964) as a further step in the evolution of forest sampling designs (Wiant, 1976). Since its introduction, and particularly in the past 10 years, it has been widely applied especially in the U.S.A. Much has been written on this efficient cruising system.

4.1 THEORY OF 3P-SAMPLING

The basic idea of the method is that some estimate of tree volume and/or value, even though it may be a poor one, is better than no estimate at all, and that these estimates can be corrected by using a small number of accurately measured samples. Furthermore, since the probability of selection of an individual as a sample is in direct proportion to prediction of its volume, the bigger and more valuable trees are sampled more heavily than smaller and less valuable trees (Space and Turman, 1976).

Grosenbaugh (1964, 1965) discussed the theory of 3P-sampling in detail. Consider a population of 'M' individuals, associated with each individual there is an objectively measurable variable 'YI' which is to be estimated. Prior to sampling the population, a rough estimate of $\sum^{M} YI$; the number of individuals in the population and the size of the largest individual (referred to as 'K' also called the number of conditional chances to include in the sample) is obtained from a previous inventory or from a reconnaissance survey. To select the sample, a list of integers i.e. random numbers (KP) is generated from 1 to 'KZ' (followed by replacement of the selected integer). Where 'KZ' is the mere addition of K+Z, and 'Z' is the number of unconditional chances to exclude the individual from being selected as a sample. This 'KZ' can be calculated from the estimated $\sum^{M}(YI)/n$, where n is the statistically desired number of 3P-samples and can be calculated from the conventional formula $n = \frac{cv^2 t^2}{E^2}$ where,

cv = co-effecient of variation i.e. relative variability of the population

t = the student "t" at a given level of probability, which is approximately 1 for the 67% level of probability and 2 for the 95% level

E = the desired sampling error.

The process of 3P-sample selection involves visiting each individual 'M' of the population. The cruiser based on his experience, assigns a relative probability 'KPI' as an integer in the range of 1 through KZ-1. Comparing 'KPI' against the random number (KP) list, an individual is selected as a sample if its 'KPI' equals or exceeds the value of its paired 'KP', otherwise it is rejected. Selected individuals are precisely measured to compute actual 'YI'.

The probability for an individual to be selected as a sample is $(YI)/\sum^{M}(YI)$. 3P-sampling gives each individual in a papulation an equal chance of being included in a set of n samples, with suitable precaution against bias and against repeated sampling of similar duplicates. Grosenbaugh (1964) considered that a biased estimate is unlikely if $Z/K^2 > (4/ESN-4/M)$ where the expected sample number (ESN) = $\sum^{M} KP/KZ$. Variance of n about ESN can be calculated exactly by $(ESN)-(ESN)^2 \quad (\sum^{M} KPI^2)/(\sum^{M} KPI)^2$ and approximately by $ESN-(ESN^2)(1/M)$.

After finishing the tally, the average ratio 'YPI' of 'YI' to 'KPI' is compiled for the 3P-samples. Thus the ratio YPI is used to correct the overall estimates i.e. $(\sum^{M}KPI)(YPI)$ should approximate the actual $\sum^{M}YI$. All the individuals having estimates greater than 'K' are termed "sure-to-be-measured trees" and their summed volumes are added to the corrected estimates refered to above.

4.2 USES

The variety of applications of 3P-sampling in the past 10 years indicates that the procedure can be used for sampling any characteristic of a forest papulation (or any other type of papulation for that matter) where a volume or value can be assigned to a prospective sample (Space and Turman, 1976). Uses of the scheme can be summarised as follows.

4.2.1 INVENTORY OF SMALL TRACTS OF TIMBER

The prime objective of introducing 3P-sampling was to improve the accuracy and efficiency in assessing the volume or value of standing timber for lump-sum sales and was first applied in the western and southern parts of the United States (Van Hooser, 1973). Sharpnack (1965) applied a Monte Carlo computer simulation that repeatedly drew a sample tree from a known papulation. Comparing various sampling statistics, he found sampling was efficient and free from bias within allowable sampling error. Similarly, comparing 3P-sampling with commonly used fixed or variable radius plots, Bonnor (1972) found 3P to be a most efficient sampling technique. Johnson et al. (1967) found far better results with 3P-sampling with dendrometry when only 35 samples were measured compared to a standard cruise involving 88 sample trees. They reported that 336 sample trees were necessary using the conventional sampling procedure to achieve a standard error equal to that of the 3P-sample. Further they found that 3P estimates of total volume and total sale value gave very small sampling errors compared to a standard cruise whether or not an optical dendrometer was used to measure the sample trees. Space (1974b) claims that much more and complete information can be obtained with 3P-samples involving 60-100 trees regardless of the size of the tract and the total number of trees in the tract.

3P-sampling can be used to great advantage for inventorying small timber tracts within which each tree can be visited. Practical illustrations of the use of this design are given in Mesavage (1965, 1971), Johnson et al. (1967), Grosenbaugh (1967b, 1968), Space (1973) and Wiant Jr. (1975, 1976). A copy of Wiant's 1975 paper illustrating the use of 3P-sampling for inventorying small tracts of forest is given in Appendix 1.

4.2.2 INVENTORY OF LARGE TRACTS OF TIMBER

Although 3P-sampling reduces the number of samples required to be measured for a specific standard error of estimate, the cruiser still has to visit every tree in the population. This may be impractical when the tract is sufficiently large. This problem was overcome by Grosenbaugh (1971) by extending 3P-sampling theory to include multistage sampling designs. He updated his 'STX' program to handle 3P data and a broad spectrum of multistage designs.

When inventorying a large tract of forest, the additional stages of sampling may be either equal probability or variable probability with 3P-sampling. The simplest form of these multistage 3P designs involve samples of selected fixed radius plots of suitable size or a variable radius plot of suitable basal area factor (BAF) in the first stage of the design. But there are other sampling designs involving three or more sampling stages and incorporating aerial photo-plots or subsamples of selected plots, points or geographical areas. Where wide variation exists in the characteristics of the population, stratification with respect to species, DBH, forest type or some other characteristic can be done before sampling, as strata with differing intensities of sampling or different plot sizes can be combined in a simgle computer run. Aerial photographs are very helpful for stratification prior to plot selection (Space, 1974a).

Point-3P sampling, proposed by Grosenbaugh (1971), is one of the most popular two stage sampling designs in use now. It involves selecting a 3P-subsample on a variable radius plot (Space, 1980a). Efficiency and utility of the design has been widely proved. Much of its use has been in updating current forest inventory. Steber and Space (1972) in a pilot test in North Florida and South Georgia, found that 406 prism plots of BAF 10 were required to determine population characteristics of 405 000 hectares of forest. Applying 3P-subsampling to these 406 plots resulted in selection of 221 trees for measurement on 93 plots giving a sampling error of $\pm 7.1\%$, of which 6.95% was attributed to the sample of the first stage. Volumes estimated with this design were reported to be much more accurate than under the conventional continuous forest inventory (CFI) system involving only prism sampling.

Van Hooser (1972) evaluated point-3P sampling using already established forest survey plots in South-West Alabama as the first stage. 3P-subsamples were taken by computer simulation. Results initiated that only 259 trees on 170 plots would have been required for a given precision of estimate compared to 6500 trees needed in the standard sample. The standard cruise had a sampling error of ±4.3%, while with multistage 3P, including the standard cruise as the first stage, the error was ±4.5%. No estimate for cost and time differential could be obtained as the subsample was drawn by computer simulation but it could be expected to be considerably in favour of 3P-sampling. Further, van Hooser (1973) conducted a field test in Central Mississippi to evaluate the field performance of point-3P sampling. From 1050 already established prism plots with a total of 10 400 trees, 342 trees were randomly selected from 258 plots as the 3P-subsample. Comparison of volume estimates revealed that volume calculated by 3P-sampling differed from that of the original inventory by only 0.06% well within the range of the calculated sampling error for the 3P-sample. The combined sampling error was ±2.8%, the error associated with the first stage estimated alone being ±2.6%. Besides precise volume estimates, accurate prediction of growth, mortality and removals was found when remeasurement of the 3P selected trees was compared with the best available current information. However this sampling design does not take into account undergrowth less than 5 inches (12.7cm) DBH at the time of measurement because no tree smaller than this was measured in the original inventory. A time study to assess fully the utility of 3P-subsampling in midcycle inventories showed that using a two man team, the measurement took 12 team weeks to complete, that is slightly more than 1% of the 106 team weeks required for the original inventory.

The procedure for Point-3P sampling is discussed by Space (1974a) and Rennie (1976). It involves using formula[1] to calculate the number of variable radious plots required and the number of 3P-subsamples to be selected from these plots for measurement. It is customary to locate the variable radius plots in a systematic manner using a random start. Large variation, if it exists, can be avoided by stratification prior to calculation and layout of the variable radius plots. In the first stage, sample trees are selected with probability proportional to basal area using a wedge prism of suitable BAF. Trees so selected are subject to 3P-subsampling in the second stage, in which trees are selected with probability proportional to prediction of merchantable or total height, which ever is more relevant to the volume of interest. Thus, the final selection of samples in this design is proportional to BA*H. Since BA*H is proportional to volume, this combined sampling design selects trees proportional to volume. Samples so selected are then accurately measured to provide the correction factors to apply to the estimated volume.

The frequency represented by each 3P selected tree in this sampling design is given by the frequency represented by the variable radius plot times the frequency of the 3P-sample. This can be calculated easily when broken down into the component parts (Space, 1980a) as follows:-

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1 Formulae for calculating number of samples required both at first and second stage is

$$E_t = \sqrt{\frac{cv_1^2}{n_1} + \frac{cv_2^2}{n_2}}$$

where: E_t = combined sampling error;
CV_1 = coefficient of variation in first stage
CV_2 = coefficient of variation in second stage
n_1 and n_2 = number of sample required in first and second stage.

Variable plot frequency (single plot) = $\frac{\text{Hectares in tract}}{\text{No. of sample points}}$ *

$$\frac{\text{Metric BAF}}{\text{Dia.}^2 * 7.854 * 10^{-5}} \text{ * Slope correct. (sec.slope) * Edge plot correct.}$$

3P-sampling frequency (single tree) =

$$\frac{\text{Estimated heights of all the trees}}{\text{No. of sample trees * Est. Ht. of particular tree}}$$

Sampling error of the first stage sets the lower limit for the total sampling error of the multistage inventory scheme and the addition to error by the 3P-sample in the second stage is generally negligible (Space, 1974a). Combined sampling error can be calculated by

$$E_t = \sqrt{E_1^2 + E_2^2 + 2W}$$

where: E_t = combined sampling error

E_1 = sampling error of the first stage (plots or prism points)

E_2 = sampling error of the second stage (3P-subsample)

W = relative covariance.

Estimated volume of a forest tract or stratum using point-3P sampling can be calculated by applying the following formulae (Rennie, 1976):

Tract volume = Area * BAF * $\overline{\Sigma H}$ * $\left(\overline{\frac{\text{Volume}}{\text{BA*H}}}\right)$ where,

Area = tract or stratum area

BAF = basal area factor for prism or angle-guage

$$\left(\overline{\frac{\text{Volume}}{\text{BA*H}}}\right) = \sum_{j=1}^{NP} \sum_{i=1}^{Mj} \left(\frac{Y_{ij}}{BA_{ij} * H_{ij}}\right) / M$$

i.e. mean ratio of tree volume (or other tree characteristic) to product of BA*H.

$$\overline{\Sigma H} = \sum_{j=1}^{NP} \sum_{i=1}^{Nj} Hij/NP$$

i.e. mean summed tree height per point.

where: NP = number of sample points

Nj = number of tree selected with prism at point j.

Hij = estimated height of tree i at point j.

Mj = number of trees selected with Point-3P sampling at point j.

BAij = basal area of tree i at point j.

Yij = Volume (or other tree characteristics) of tree at point j.

$M = \sum_{j=1}^{NJ} Mj$; total number of trees selected in the area by point-3P sampling.

Relative variance of volume can also be approximated (Rennie, 1976) by:-

$$S^2_{\text{tract volume}} = \frac{S_1^2}{NP * (\overline{H})^2} * \frac{S_2^2}{(\sum_{j=1}^{NP} Mj) * \left(\frac{\overline{Vol}}{BA*H}\right)^2} \quad \text{where,}$$

$S^2_{\text{tract volume}}$ = approximate variance of tract volume as proportion of tract volume.

S_1^2 = variance of summed tree height/point.

S_2^2 = variance of ratio of tree volume (or other tree characteristic) to product of basal area times estimated height.

Variable radius plot sampling selects trees with probability proportional to size, which in an efficient sampling procedure for unevenaged stands. Incorporation of this procedure with 3P-sampling provides an even more efficient and accurate sample (Space, 1974a).

Fixed radius plots are efficient in sampling evenaged stands. Where needed, 3P-sampling can be incorporated to increase the efficiency and accuracy of estimate. A similar two stage sampling design, as discussed for variable radius plots, could be used on fixed radius plots by estimating the volume of each tree on the plot and selecting a

3P-subsample based on estimated volume. Bonnor (1972), comparing 3P with fixed or variable radius plots, found that 3P was efficient with respect to sample variance and time. Further, he found that efficiency was increased when 3P-sampling was incorporated with fixed radius plots in the second stage sampling.

CFI, an inventory system yielding reliable estimates of volume growth on forests, has been of limited use in many places due to the cost involved. Kunz and Rennie (1976) evaluated the precision and potential cost saving associated with 3P-sampling at alternative remeasurements of CFI fixed area plots in Ames plantations. Results confirmed 3P-sampling as an acceptable procedure to estimate current volume of trees present at a previous measurement of the CFI system. A small increase in sampling error occurred but was acceptable because 121 trees on 77 plots were measured using 3P-sampling compared with 2063 trees on 151 plots in the routine CFI System.

Beside the multistage sampling designs discussed above, other efficient schemes involving 3P-subsamples are recorded in the literature. Dippold (1974) re-inventoried a large tract of forest in Alaska by sub-dividing 121 cutting units on photographs into 768 areas of equal volume. Each area contained a volume usually assessed to be equal to that of a fully stocked 10 acre stand. Thirty five of these areas were selected at random and identified on the ground. A 3P-subsample of these constituted the sample of the second stage. Standing net volume of the sample trees was assessed accurately. Estimated gross volume for sample areas was obtained by adding the individual estimated volumes. These were then adjusted to net volumes by multiplying the total by the ratio of actual to predicted volumes obtained from the sample trees. This inventory of 4886 hectares was completed in 17 days and provided a volume estimate with a sampling error of ±5%.

It is seldom necessary or feasible to design a sampling scheme involving more than two sampling stages when all the sampling is to be carried out by field measurement. However, when aerial photographs are available, a type of multistage sampling can be conducted by establishing a large number of first stage photo-plots. These photo-plots are cheap to establish and assess in comparison to ground plots. This use of photos in the first stage can also reduce large variation in the sample and thus greatly improves the first stage sampling error which is generally the controlling error in multistage sampling designs (Space, 1980a). Theoretical development and increasingly finer resolution of photo imagery has made it possible to employ remote sensing imagery successfully in multistage sampling designs. Using 3P-sampling, first-stage samples are randomly selected from space or aircraft imagery. Large scale photographs with increasingly higher resolution, are obtained for subsamples in subsequent sampling stages. In these subsequent stages, 3P-sampling is again used to select subsamples. Finally the selected samples are located on the ground to obtain valid estimates for the entire area. Estimates obtained through this procedure have been shown to be unbiased and the sampling error depends solely on the accuracy of the prediction made at each stage (Langley, 1969; 1971). Furthermore, after a pilot inventory involving five-stage sampling, incorporated with 3P-sampling, conducted on 4 million hectare of land in Arkansas, Georgia, Louisiana and Mississippii, using photographs taken from the Appollo space craft, Langley et al. (1969) recommended wider use of the 3P multistage design involving space photographs. To increase sampling efficiency, Langley used space photo in conjunction with 1/60 000 scale polaroid, 1/20 000 scale 70mm and 1/2000 scale 70mm color aerial photographs in a stratified five stage probability sampling design including a 3P-subsample. Although this design yields unbiased estimates independent of the quality of imagery, sampling error is inversly related to the quality of the photo data. Best results were obtained for the Mississippii area where 58% reduction in sampling error was attributed to the quality of information yielded by the Appollo 9 photography.

A similar multistage sampling design involving the establishment of a large number of cheap photo-plots, to reduce sampling error, was developed by Wiant (1974). Volume on fixed radius plots or sum of heights on variable radius plots was estimated on the ground of the final selection of imagery plots. Using these estimates, a sub-sample of trees on these plots was selected for further 3P cruising. All these trees were measured and the volume estimate was computed and extrapolated to the whole area.

4.2.3 3P LOG-SCALING

3P log-scaling was proposed and successfully tested by Space (1969) and is finding increasing use. Further tests by Johnson et al. (1971) established that 3P log-scaling may be a very efficient method of providing precise estimates of volume at low cost compared to measurement of all logs where high variability in log size or value precludes simple random sampling of the log load. Assuming a coefficient of variation in volume of log of 20%, 100 individuals may need to be measured for a desired sampling error of ±2%. Johnson et al. (1971) also developed a computer program to process such 3P log-scale data.

Rupp (1976) described in detail the procedure for 3P log-scaling. The log scaler quickly guesses the small end diameter and length of each log on the load. These quesses are translated into estimated gross volume, which is compared with the random number list drawn for the log-scaling. Logs with estimated volume equal to or greater than the paired random number are selected as samples. Detailed measurements of each sample log provides the actual volume of the log. The average ratio of estimated to actual volume is calculated and is then used to correct the overall estimated volume of the logs. This provides an efficient and cheap method of log-scaling.

Chehock and Walker (1975) extended the use of 3P-sampling to draw a subsample of logs for detailed measurement combined with sample weight scaling of the log loads. This enabled volume by product classes to be obtained. The time required to determine the volume of the sample load was reduced with improved accuracy of the final calculated volume. This method employs multistage sampling, the first stage being the load of logs as it arrives in the mill log-yard and the second stage being the 3P-sample of logs.

4.2.4 USES OF 3P-SAMPLING IN RELATED FIELDS OF FORESTRY

3P-subsampling on transects, to inventory logging slash fuels before and after fire treatment, was conducted by Beaufait et al. (1974). The system is best suited to material oriented parallel to the ground. The method used in the study involved line intercept counts to compute fuel volume, weight and surface area. 3P-sampling was used to assess twigs of diameter up to 1cm.

Wiant and Michael (1978) discussed the potential of 3P-sampling in wildlife and range management. They concluded that the method can be used efficiently in estimating fruit, mast and seed production, in the census of wildlife and in studies of wildlife habitat.

4.3 RANDOM NUMBER GENERATION

The random number list for selection of the 3P-sample can be generated in a number of ways. However to avoid introduction of bias, a custom generated list of random numbers for the specific sampling problem is recommended. Grosenbaugh (1965) developed a program 'THRP', which was later superseded by 'RN3P' to generate a list of random numbers based on the number of trees to be sampled and 'KZ' which is the estimated total volume divided by the number of 3P-samples needed.

4.4 MEASUREMENT OF 3P-SAMPLE TREES

Any method of measuring trees can be used depending upon the precision and accuracy required for the inventory (Space & Turman, 1976). Volume of the 3P-sample trees can be obtained from volume tables or functions. However, for most precise estimates, it is advisable to measure the tree directly. Hazard and Berger (1972) reported that volume table biases were commonly introduced into the volume estimate where sample trees were not measured directly.

4.4.1 MEASUREMENT THROUGH FELLING, BUCKING AND SCALING (FBS)

To measure sample trees precisely, they can be felled and bucked into appropriate logs before measurement. This method is generally prescribed for areas where the possibility of considerable unseen defect and breakage exists at the time of harvest. Since felling, bucking and scaling is not physically convenient and involves high costs and, on the other hand, sampling fewer trees increases sampling error, this method can only be used with 3P-sampling rather than with the more conventional sampling methods. The FBS method is used by the Bureau of Land Management in Western Oregon (Johnson and

Hartman, 1972). Apart from areas of forest with trees of unseen defects and high breakage danger, the FBS system may be feasible in other forest areas where 3P-sampling is used.

4.4.2 STANDING TREE MEASUREMENT

(a) Measurement by optical dendrometry: Introduction of optical dendrometry and 3P-sampling technique, which has reduced the number of samples required without imparing the accuracy of the inventory, has made it possible to measure standing trees precisely and rapidly (Steber and Space, 1972). Among the several type of instruments available, the Barr and Stroud dendrometer and Telerelaskop are probably the best known. Unfortunately, the Barr and Stroud is costly and is no longer being manufactured. However, the US Department of Agriculture and Forest Service, is currently developing an instrument which can serve both as a surveying instrument and an optical dendrometer (Space, 1980b) which, hopefully, will replace the Barr and Stroud instrument.

Dendrometers can be manipulated to measure a tree by dividing it into many sections. This enables the actual volume outside bark of each section to be calculated precisely, which by simple addition, gives total tree volume. Dendrometers have the capability of measuring accurately, forked, leaning or bent trees and can also be used to calculate the volume of culled sections.

Detailed procedures for measuring sample trees with optical dendrometers to calculate volume are given by Mesavage (1971); Grosenbaugh (1974) and Space (1974b).

(b) Measurement by Spiegel Relaskop: The high cost of dendrometers and the complicated processing program limits the use of dendrometry in forest inventory (Wiant, 1976). To overcome this problem a very practical combination of the relatively inexpensive Spiegel Relaskop in conjunction with the height accumulation method of volume determination developed by Grosenbaugh (1954) can be used. This method has been discussed by Arney and Paine (1972) and Wiant (1976). Results using the Relaskop have been shown to be comparable with those obtained using the highly accurate Barr and Stroud dendrometer (Arney and Paine, 1972; Yocum and Bower 1975).

4.5 DATA PROCESSING SYSTEM

Simple 3P inventories employing a volume table or function can easily be compiled by hand, but large scale forest inventories are generally too complicated for this and processing by computer is necessary. Systems for processing, need to be tested and revised before they are made fully operational. To avoid this cumbersome job, a generalized computer programme 'STX' developed by Grosenbaugh (1967a, 1974) and modified by Space (1974a) can be used to process data from a wide range of sampling designs and dendrometry methods. This program is fully debugged, efficient and can be used on both large and small computers. As a generalized system, it is not limited to specific product grades or utilisation codes, fixed or variable radius plots and measurement units. It uses data from dendrometry, but can be modified easily to use volume tables or functions if desired. Thus, it can process any valid inventory design up to 3 stages, employing either fixed or variable probability sampling at each stage. This program converts dendrometer and or direct measurements of the sample tree to primary units of measurement, projects the unseen portion of the tree bole and interpolates to a specified top diameter. Frequency of each sample tree is calculated and volume for each stratum, species, product and grade is computed, providing conversion co-efficients enables volume or value for the product or mill outturn to be calculated by the program (Grosenbaugh, 1973; 1974).

4.6 ADVANTAGES OF 3P-SAMPLING

3P-sampling is a sampling technique which has widespread application in quantity estimation in forestry and many other fields. Its cost efficiency is a boon to the forester. The system can be used for forest cruising, log-scaling and any other application where a relative volume, weight, size or value can be assigned to the population.

As 3P-samples are selected in direct proportion to prediction by visitation of the whole population or a large part of it, sampling error is reduced tremendously. Consequently, far fewer 3P-samples need to be selected for a given precision of estimate. This makes more time available for precise measurement of the selected sample. The detailed measurement of tree characteristics derived by dendrometry or direct measurement not only eliminates sampling and technique errors, associated with conventional volume tables and equations, but also, by use of conversion co-efficients, enables determination of net volume, product volume and value. Furthermore, as far fewer samples are required, a considerable saving in time and cost results (Space, 1974b). Lund (1976) suggests that 3P-sampling may well be the best system to use for inventory of forest stands, homogeneous in species composition, but with large variation in tree size. For stands in which the composition of species is heterogeneous, some other sampling technique may need to be considered.

CHAPTER 5

CASE STUDIES OF 3P-SAMPLING

Three case studies in P.radiata plantation forests of the Australian Capital Territory are described to illustrate the methodology involved in applying 3P-sampling to forest inventory. The studies relate to estimating volume in small forest plots, in a forest compartment and in a load of logs.

5.1 CASE STUDY 1: 3P CRUSING (100% VISITATION) OF A FOREST PLOT

This study was conducted in a plot (approximately 1ha) of 32-year-old plantation grown radiata pine in compartment 80, Stromlo Forest, A.C.T. The plot was divided into three parts of approximately equal size, each plot being cruised by a party of three students, in the M.Sc. forest management class, ANU.

The forest stand in question was homogenous and experience in similar stands suggested that the coefficient of variation (cv) of tree volume would be about 25%. Using this value, the number of 3P-sample trees needed to obtain a sampling error (E) of $\pm 5\%$ at the 66% level of probability (t=1) was calculated using the formula $n = \frac{cv^2 t^2}{E^2}$. Substitution in the formula indicated that 25 sample trees were needed.

The area was then reconnoitred quickly to estimate the total number of trees in the tract, the approximate volume of the largest tree and the tree of average size and, hence, the total volume on the tract. The estimates were 300 stems, 250 (m^3 x 100), 80 (m^3 x 100) and 24 000 (m^3 x 100) respectively. Using these estimates, 'KZ' was calculated:

$$KZ = \frac{\text{estimated total volume}}{\text{desired number of samples (n)}}$$

A list of random numbers between 1 and 'KZ' was then generated using a TI 59 calculator. Numbers having a value greater than 'K' were recorded as 'nulls'.

The area was then traversed by the assessment teams. As each tree was visited, the assessor estimated its volume by eye and the tallyman compared the estimate against the next random number on the list. Four outcomes were possible:-

(i) Random number a null in which case the crew passed on to the next tree.

(ii) Estimated volume $<$ random number. Crew passed on to the next tree.

(iii) Estimated volume $\geqslant$ random number. In this case, the tree was selected in the 3P-sample and measured accurately for DBHOB and total height. Volume (m^3 x 100) was derived using the Stromlo tree volume function.

(iv) Estimated volume $\geqslant$ 'K'. Tree a 'sure-to-be-measured' tree. DBHOB and total height were measured accurately and volume (m^3 x 100) was derived using the Stromlo function.

The volume estimates and measurements were recorded on forms (Fig. 5.1) specially designed for simple 3P-sampling by Space (1973). The forms which require only a basic background in mathematics, simplify the manual processing of the data and calculation of the sampling error.

After the assessment was completed, data sheets of the three teams were combined and statistics for the tract were calculated (Fig. 5.2). Volume calculated was $24.7m^3$ with a sampling error of $\pm 5.9\%$. This error limit is slightly greater than the $\pm 5\%$ prescribed.

This particular study was a teaching exercise which occupied one day. It was apparent to the class that with experience, assessment could have been completed and results processed by a crew of two men in a matter of half a day.

THREE-P CRUISING

FIELD SHEET

Sale Name Test

Stratum Pine Cruiser ANU M.Sc. Class Date 2.4.80

Species Pine				
Measured Volume 3-P	Measured Volume 100%	Estimated Volume	Measured/ Estimated	$(M/E)^2$
	53			
		120		
		20		
		80		
		160		
		40		
		60		
		40		
96.66		90	1.074	1.153
		60		
		10		
		150		
		140		
86.0		80	1.075	1.156
		60		
		110		
		100		
		70		
		20		
		90		
		120		
161.35		175	0.922	0.850
		65		
		10		
Sums	53	1870	3.071	3.159
		Number of Samples	3	

Species Pine				
Measured Volume 3-P	Measured Volume 100%	Estimated Volume	Measured/ Estimated	$(M/E)^2$
		150		
		60		
		90		
		15		
		10		
120.96		140	0.864	0.746
		10		
		100		
		120		
		90		
		25		
		20		
		30		
		80		
		120		
		70		
		90		
		110		
		10		
		100		
		80		
		20		
		120		
		120		
Sums		1780	0.864	0.746
		Number of Samples	1	

Fig. 5.1 Field form for recording 3P-cruise data

THREE-P CRUISING

SUMMARY SHEET

Sale Name Test Stratum Pine All Teams Date 2.4.80

Species			
*1. Sum of Measured/Estimated Volumes	24.3877	Σx	
*2. Sum of Estimated Volumes	22255		
3. Line 1. x Line 2.	54274.2630		
*4. Number of 3-P samples	22	n	
5. Three-P Volume = Line 3. / Line 4.	24670.376		
*6. 100% Measured Volume	53		
7. Total Volume = Line 5. + Line 6.	24723.376		
*8. Sum of (Measured/Estimated)^2	29.044	Σx^2	
9. Line 8. x Line 4.	638.968	$n\Sigma x^2$	
10. (Line 1.)^2	594.759	$(\Sigma x)^2$	
11. Line 9. / Line 10.	1.0743	$\frac{n\Sigma x^2}{(\Sigma x)^2}$	---Call this 'A'
12. Line 11. - 1.0	0.0476	A-1	
13. Line 4. - 1.0	21	n-1	
14. Line 4. / Line 13.	1.0476	$^n/_{n-1}$	---Call this 'B'
15. Line 14. x Line 12.	0.0778	B*A	
16. Square Root Line 15.	0.2789	B*A	
17. Coefficient of Variation= Line 16. x 100	27.89	$100\sqrt{B*A}$	
18. Square Root Line 4.	4.6904	$\sqrt{n}$	
19. Sampling Error % = Line 17. / Line 18.	5.9461	$^{cv}/\sqrt{n}$	

* From field sheets

Fig. 5.2 Form for office compilation of simple 3P-cruises

5.2 CASE STUDY 2: POINT-3P SAMPLING OF STANDING VOLUME IN A FOREST COMPARTMENT

This study was conducted in compartment 80, Stromlo Forest A.C.T. Area of the compartment is 18.2 hectares. The aim of the study was to assess the standing volume of timber (10cm top DUB) in the compartment using two-stage sampling. This consisted of variable radius plots (BAF 4) as the sample of the first stage and trees selected by 3P-sampling as the sample of the second stage. Such a design is commonly called point-3P sampling. The 3P-sample trees were measured by Barr and Stroud dendrometer and the data were processed by the 'STX' computer program.

The first step was to calculate the number of variable radius plots of BAF 4 and the number of trees to select from these plots by 3P-sampling (for measurement by dendrometer) to achieve a total sampling error of not more than a specified $\pm 9\%$ two times in three i.e. 66% level of probability.

A coefficient of variation of stand volume of 60% was assumed for the variable radius plots. It was also assumed that if the estimate of tree volume on the plots was based on the relationship of height to actual volume, a coefficient of variation of about 20% would result for the ratio of estimated to actual volume of the 3P-sample trees. These figures were then used to calculate the number of variable radius plots and 3P-trees required by substitution in the formula:-

$$E_t = \sqrt{\frac{cv_1^2}{n_1} + \frac{cv_2^2}{n_2}}$$

where E_t = total sampling error.

cv_1 = coeff. of variation of the BAF 4 variable radius plots.

CV_2 = coeff. of variation of ratio of estimated to actual volume of the 3P-sample trees.

n_1 = number of BAF 4 variable radius plots required.

n_2 = total number of 3P-sample trees required on the n_1 plots.

A number of solutions was possible but it was decided that at least 20 3P trees should be selected. With this constraint, the combination of 56 plots and 25 trees (3P-sample) from these plots was chosen as the best to adopt.

The next step was to reconnoitre the compartment quickly and estimate the average count of trees per variable radius plot (BAF 4), the average total height of the stand, the height of the tallest tree i.e. 'K' and heights of all trees in the plots to be sampled. The estimates were 6 trees, 26m, 33m and 8736m (i.e. 6 trees x 26m x 56 plots) respectively.

$$\text{Thus, } KZ = \frac{8736}{25} = 349$$

The values 'K' and 'KZ' were then fed into program 'RN3P' to generate a random number list for selecting 3P-sample trees from the variable radius plots (Appendix 2).

The field procedures involved laying a systematic grid of appropriate dimensions over a map of the compartment to establish the location of the variable radius plots. The location of the first plot was determined at random. The centre of each plot was subsequently located by ground survey and marked.

Assessment involved taking an angle-count sweep at each plot centre and estimating the total height of each tree counted in the sweep. The random number list was then consulted to determine whether or not counted trees were 3P trees. As for case study 1, four outcomes were possible:-

(i) Random numbers a 'null'. Pass on to next tree.

(ii) Estimated height $<$ random number. Pass on to next tree.

(iii) Estimated height $\geqslant$ random number. Tree is a 3P-sample to be measured by dendrometry.

(iv) Estimated height $\geqslant$ 'K'. Tree a 'sure-to-be-measured' tree. Measured by dendrometry.

An example of the recording sheet used is given in Figure 5.3. The following data were recorded at each plot centre:-

Tree No: The identification number (consecutive from 1) of each tree counted.

Ht: Estimated height of each tree counted in the sweep.

Stratum: 1 for pine, 2 for other species. In this instance all trees were pine.

'*,=': '*' for tree selected for dendrometry by 3P-sampling. '=' for 'sure-to-be-measured' trees.

Class: 'RP' for radiata pine. No other species were encountered in Cpt. 80.

DBH: Diameter over bark at breast height (1.3m).

EXTR: Slope or edge correction if any. If both applied, they were multiplied together (secant of slope * edge plot correction) before entry.

Term: '*' for unmerchantable tree: in this study, any tree $<$13cm DBHOB.

Point No: Plot or point number or other sampling unit identification.

Misc: For recording general comments.

THREE -P FOREST INVENTORY
Tree Data

← All Trees → ← 3-P Sampled Trees → ← All Trees →

Tree No. (1–4)	Ht. or Vol. (6–9)	Str (10)	* = (11)	Class (12–15)	D.B.H. (19–21)	Opt. M (23)	Opt. B (24)	Opt. U (25)	Opt. I (26)	Bark A (27–30)	Bark B (31–34)	U_{ML} (36–38)	U_{DT} (39–41)	XTRA Cor. (52–56)	Term (72)	Point No. (77–80)	Misc.
1	26	1		RP	36.5									4.1104		29	Line 6 P.T.1
2	24	1			29.9												
3	25	1			36.5												
4	23	1			32.9												
					.												Line 6 P.T.2
1	27	1			37.4											30	
2	27	1			36.0												
3	26	1			32.9												
4	27	1			44.5												
5	25	1			35.1												
					.												Line 6 P.T.3
1	25	1			43.1											31	
2	25	1			41.8											31	
3	24	1			35.5											31	
					.												Line 6 P.T.4
1	25	1			35.5											32	
2	24	1			29.0												
3	20	1			34.9												
4	25	1			37.5												
5	26	1			31.5												
6	24	1			41.8												
7	27	1			42.7												
					.												Line 6 P.T.6
1	25	1			43.8											33	
2	26	1	*		48.0												
3	21	1			31.0												
4	25	1			44.9												
					.												Line 6 P.T.6
1	24	1			37.9											34	
2	25	1			44.0												
3	25	1			40.0												
4	21	1			27.5												
5	25	1			43.5												
					.												

Fig. 5.3 Tree data field sheet illustrating how data are recorded in Point-3P sampling

DENDROMETRY OF THE 3P-SAMPLE TREES

Dendrometry of trees selected by 3P-sampling was conducted using a Barr and Stroud Model FP-15 Short-base range finder dendrometer. Data were recorded in the format described by Space (1975, p 15-23) and a sample is appended (Fig. 5.4). As the data were to be processed by the 'STX' program, information relevant to the processing was also recorded on the same data sheets. This information included options such as type of instrument used, bark function to correct overbark to underbark diameter, projection of unseen sections of the stem and interpolation of specified top and intermediate diameters.

The dendrometer was set up approximately 25m from each sample tree at a position which gave a good view of the bole and tip. Trios of measurements (true coincidence, false coincidence and sine of the angle of elevation/depression) were taken at a series of points along the bole, beginning at 3m and working upwards to the tip. At least six readings by dendrometer were taken on each tree. Measurements at stump (15cm above ground) and breast height (1.3m) were measured directly.

Since a local grading system and conversion co-efficient for radiata-pine was not available, the following product specifications were used.

PW: Pulpwood or particle board material (too small to be sawn into lumber). Minimum top dia U.b. 7cm (7.6cm O.b.). Large trees which were extremely limby, forked or otherwise would not make sawn timber, were placed in this grade.

SW: Material suitable as saw logs. Minimum top dia. U.b. 15cm (17cm O.b.). Minimum length 4.8m. Maximum length 6.0m.

VL: Log suitable for veneer (peeling). Minimum top dia. U.b. 40cm (44cm O.b.) and fixed length of 5.2m.

TW: Pulpwood or particle board material in tops of tree containing saw logs or veneer logs. Minimum top diameter as for PW.

XX: Cull material not making any product.

UU: Unutilized material (usually tops) which would be left on the forest floor.

The data were processed on the ANU UNIVAC 1100/82 computer and a sample of the output is given in Appendix 3.

Results summarised in Appendix 3, Table 4 indicate that the volume of timber on the tract is $3112 m^3$ (under bark) with a standard error of $\pm$ 2%. This error limit is well below the specified limit of $\pm$9%. Appendix 3, Table 7, gives summary of grade-yield for each product specification. This information was obtained by inputting special codes to the computer package 'STX'. Table 8 and 9 of Appendix 3 summarise the volume yields for grades SW (stem wood) and TW (top wood) by DBH classes. Similar grade-yield summaries were obtained for other product specifications PW, UU and XX.

This particular study was a teaching exercise which involved the M.Sc. class of ten students over a period of two and a half days. With experience, a team of 3 men would complete the exercise in 1.5 or 2 days.

THREE-P FOREST INVENTORY
Dendrometry data

FIGURE 4

Crew Student of M.Sc. ANU

Date ______

TREE NO. 1–5: 3, J: 1

Cols. 1-4, 73-80 are in every card.

Card	Col.	T GRADS (12)	F GRADS	SINELV	GR (26)	TERM (+ *) (72)	LEAN deg.
1		-999	46.0	1.15			
	27		41.7	1.150	SW		
	42	467	763	09270	SW		
	57	472	718	11960	SW		
2		482	678	13890	SW		
		495	670	14700	SW		
		505	613	15640	SW		
		511	584	16135	TW		
3		522	523	16775	UU		
						*	
4							

GROWTH (73–76): 3.1

CFI POINT NO. (77–80): 7

Sketch tree below:

For unseen material, total tree ht ______, unseen merch. length ______, rate of taper ______

Dendrometer set up: bearing ______ distance ______

TREE NO. 1–5: 1, J: 1

Cols. 1-4, 73-80 are in every card.

Card	Col.	T GRADS (12)	F GRADS	SINELV	GR (26)	TERM (+ *) (72)	LEAN deg.
1		-999	40.5	1.15			
	27		35.5	1.150	SW		
	42	470	735	09940	SW		
	57	476	697	10950	SW		
2		482	695	13250	SW		
		490	621	13580	TW		
		492	601	14520	TW		
		518	519	16240	UU	*	
3							
4							

GROWTH (73–78): 2.5

CFI POINT NO. (77–80): 10

Sketch tree below

FIGURE 5.4 Field form for recording dendrometry data

5.3 CASE STUDY 3: 3P-SAMPLE LOG-SCALING

3P-sampling which originally developed for timber cruising, has proved time and cost efficient when applied to log-scaling and is being usefully applied in a number of countries.

This study was conducted in the log-yard of the Monier Sawmilling Co., Fyshwick, A.C.T. on a stack of 217 logs of radiata pine each of length 3.8m. The aim of the study was (1) to estimate the volume of timber in the stack by 3P-sampling and (2) to estimate the effect of various sampling intensities on the sampling error.

Each log in the stack was numbered on both ends, the number running consecutively from 1 to 217. End diameter of each log were then estimated by eye and recorded. Following this, the end diameters were measured directly by tape and actual volumes were derived using Smalian's formula.

Based on experience with previous stacks, and using D^2 as an estimate of volume, the value of 'K' i.e. the largest D^2 expected in the stack was taken as 1025 (i.e. $32^2 + 1$) and the sum of the squared diameters was estimated as 89 600. A range of sample sizes i.e. 5, 10, 15, 20, 25, 30, 40, 50, 60 and 80 logs was chosen for investigation. These corresponded to a 'KZ' value of 17 920 (i.e. 89 600/5), 8960, 5973, 4480, 3584, 2987, 2240, 1792, 1493 and 1120 respectively. Using these data and the 'RN3P' program, lists of random numbers were generated for 3P-sampling.

The next step involved writing a simple computer program to calculate:-

(i) Actual volume of each log from the direct measurements of end diameters using Smalian's formula.[1]

(ii) The square of the estimated diameter at both ends (D_1 and D_2) of each log and of the average diameter.

(iii) Volume of each log based on the estimated diameters D_1 and D_2 respectively using Huber's formula.[2]

(iv) Volume of each log based on both estimated end diameters using Smalian's formula.

(v) Ratio of actual to estimated volume for all trees subsequently selected as 3P-sample trees.

For each size of sample, the estimated log diameter squared (D_1, D_2 and average of D_1 and D_2 respectively) was compared with the appropriate random number list to determine the 3P-sample trees. Four outcomes were possible in each case.

(i) Random number a 'null' in which case one preceeded the next log.

(ii) Estimated diameter squared $<$ random number. Proceed to the next log.

(iii) Estimated diameter squared $\geq$ random number. In this case, the log was selected in the 3P-sample.

---

1 Smalian's formula $v = \frac{S + s}{2} * L$

2 Huber's formula $v = S_{1/2} * L$

where: S = cross-sectional area at large end of log.
s = cross-sectional area at small end of log.
$S_{1/2}$ = cross-sectional area at mid length of the log.
L = log length.

(iv) Estimated diameter squared $\geqslant$ 'K', log regarded as a 'sure-to-be-measured' log whose volume is calculated separately and added to the final 3P estimates.

For a given sample size, the ratios of actual to estimated volumes of the 3P-sample logs were added and averaged. This average was then used to correct the total estimated volume of the log stack. Finally, the coefficient of variation of the log volume estimate was calculated using the formula:

$$CV = 100 \sqrt{\frac{n}{n-1}\left(\frac{\sum x^2}{(\sum x)^2} - 1\right)}$$

where: n = number of 3P-sample selected

$\sum x^2$ = sum of squares of the ratio of measured to estimated volume.

$(\sum x)^2$ = square of sum of ratios of measured to estimated volumes.

Sampling error (SE) was then calculated from the coefficient of variation using the formula $SE = CV/\sqrt{n}$.

Results, which are summarised in Table 5.1 and illustrated in Figure 5.5 indicate:

(i) The standard error of the estimate decreases rapidly with increase in sample size from 5 to 30 units but, beyond this, the reduction is too slight to justify the cost of extra samples.

(ii) For a given size of sample, the standard error of the volume estimate based on both end diameters (D_1 and D_2) is lower than that based on diameter at either end.

(iii) Holding the standard error of the estimate to 2.5% requires approximately 33 samples based on both end diameters (D_1 and D_2) and 45 to 60 samples when based on diameter at either end. The latter option would be quicker and hence less costly to apply - estimation of both end diameters involves more time because, in a log stack, the paired ends have to be identified before estimation can proceed.

Examination of the basic data reveals that of the 217 logs in the stack, the larger end corresponds with end 1 and end 2 in 105 (48%) and 107 (49%) of the cases respectively. Thus, uneven distribution of large (or small) ends in the log stack cannot explain the apparent difference in standard error between the D_1 and D_2 curves at high sampling intensities (Fig.5.5). However, the two curves almost coincide in the region of practical sample intensities.

Table 5.1 Summary of Volume Estimates and Other Statistics for the Different Sampling Intensities

Size of 3P-sample Nominal	Actual	Basis of estimate*	Est. volume + (m^3)	CV(%)	SE(%)
5	6	1	27.1	16.4	6.7
	6	2	26.4	15.3	6.2
	6	3	26.8	14.9	6.0
10	13	1	27.0	19.2	5.3
	12	2	28.3	16.5	4.8
	11	3	27.3	13.5	4.0
15	18	1	27.5	18.7	4.4
	17	2	28.5	23.8	5.8
	19	3	28.0	15.8	3.6
20	30	1	29.0	17.5	3.2
	26	2	28.9	16.2	3.2
	29	3	28.5	15.5	2.3
25	21	1	27.6	19.3	4.2
	16	2	27.0	19.1	4.8
	19	3	28.4	19.0	4.4
30	44	1	29.6	17.2	2.6
	39	2	30.0	22.4	3.6
	42	3	29.8	15.3	2.4
40	38	1	28.9	22.4	3.6
	36	2	28.6	15.8	2.9
	36	3	28.6	16.2	2.7
50	62	1	29.9	20.0	2.5
	57	2	29.4	22.7	3.0
	59	3	29.1	13.3	1.7
60	74	1	28.5	17.2	2.0
	69	2	28.8	23.6	2.8
	71	3	28.4	14.9	1.7
80	89	1	28.5	19.5	2.1
	86	2	28.8	18.8	2.0
	87	3	28.7	12.0	1.3

* 1 = Diameter end 1
2 = Diameter end 2
3 = Diameter of both ends.

\+ Measured volume of log stock = 29.1m^3

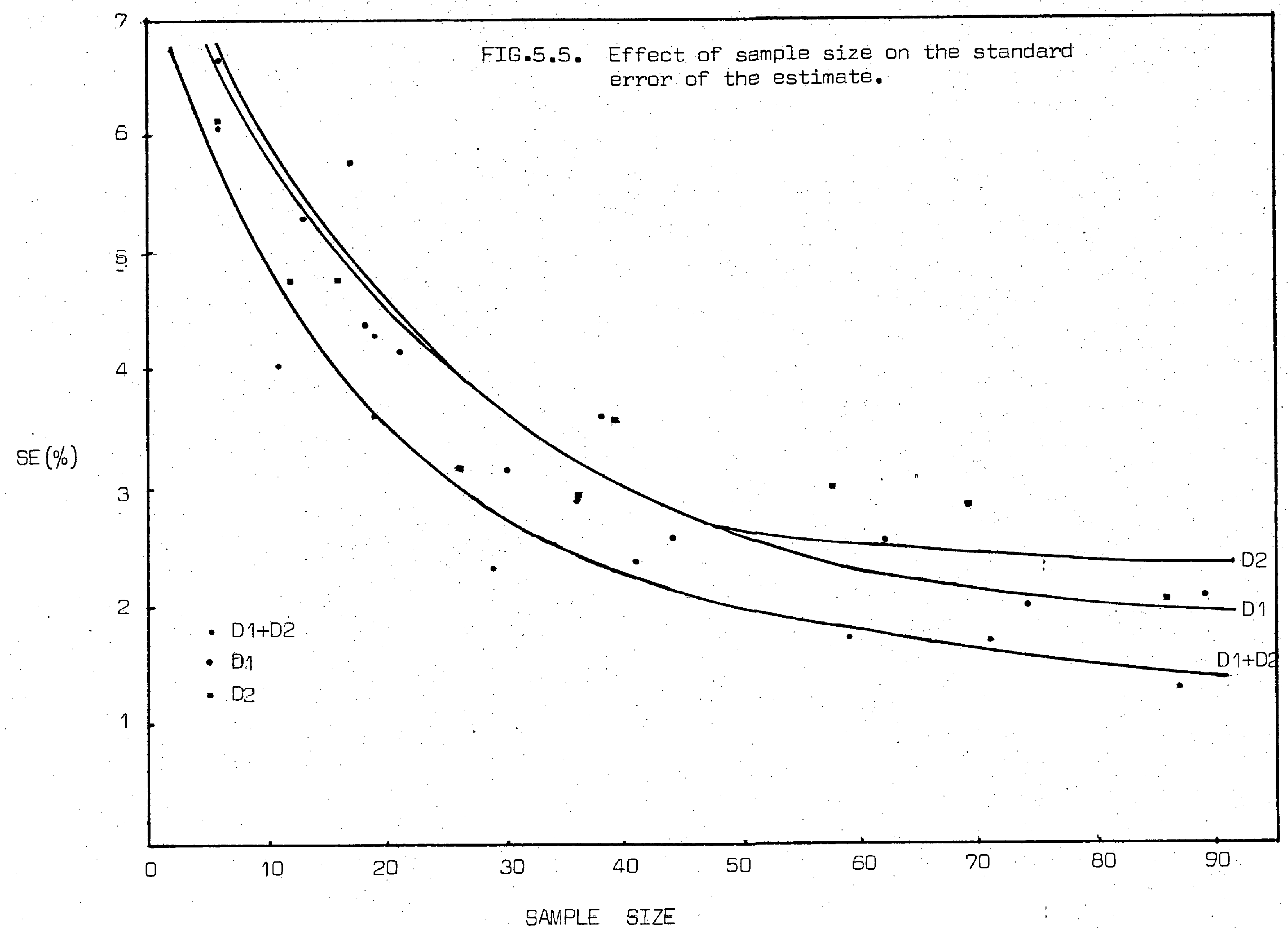

FIG.5.5. Effect of sample size on the standard error of the estimate.

CHAPTER 6

POTENTIAL OF 3P-SAMPLING IN THE FORESTS OF PAKISTAN

As mentioned earlier, Pakistan has only 3.7% of its land area under forests which is insufficient both to meet the domestic consumption of wood and to protect the land and water resource of the country. Because of the unavailability of large tracts of land suitable for afforestation, the main area for increasing production is through improved management of existing resources. This can only be achieved if better and more complete resource information is available. This necessitates that the inventory methods presently used in the forests of Pakistan be revised to give improved precision and cost efficiency.

In Chapter 4, the advantages of 3P-sampling and its uses in forest inventory, particularly in the United States of America, were revised. It is apparent that the technique, when used alone or in combination with other sampling schemes, has marked advantages in terms of cost, time and efficiency. Thus it appears to have real potential for improving the assessment of the forest resource in Pakistan. Bearing in mind rapidly improving access to computer facilities in the country, much quicker data processing will be feasible. Possible applications of 3P-sampling in Pakistan's forests are discussed below.

(a) Estimation of timber in compartments for sale

The standard procedure for estimating the volume of timber in the forest compartments in Pakistan involves measuring the DBH of each tree at the time of marking for removal and computing the volume using a 1-way volume table. Such a procedure is cumbersome when a large area of forest is involved. With the intensive management now being practised in parts of Pakistan, areas of forests are being clearfelled and regenerated artifically. There is an obvious scope for 3P-sampling in estimating the volume of timber for sale from areas proposed for clear felling. There is even scope for 3P-sampling in forests still being managed under the selection system.

(b) Regional and national forest inventory

Forest inventories conducted in Pakistan are mostly regional in nature, the prime objective being to provide estimates of timber available for exploitation during specified planning periods. No efforts has been made as yet to collect national forest resource data. The result is that some areas such as the riverine forests and irrigated plantations has not yet been covered by inventory. This is unfortunate as national data are needed to provide a sound basis for the development of resource and wood based industries (Qazi, 1978). Efficiency of present prism (angle-count) sampling procedures, in some cases supplemented by two phase sampling using aerial photography, could be improved considerably by incorporating 3P-sampling procedures e.g. multistage point 3P-sampling or fixed radius plot-3P sampling (see Chapter 4).

(c) 3P log-scaling

Measurement of each and every log is costly and time consuming and there is a possibility of bias in converting the measurements to volume using conventional log tables and functions. 3P log-scaling can be used to give precise estimates of log volume at minimum cost and would seem to have immediate application in Pakistan.

(d) Use of 3P-sampling in reforestation and reclamation works

Productivity from agriculture in the plains of Pakistan, is mostly dependent on the availability of water from various dams, which in turn, depends on the condition of the catchments. As higher consumption of wood leads to a greater exploitation of the forest resource, it becomes necessary to restock deforested areas as quickly as possible. Reclamation work is the responsibility of the forestry departments and sometimes other departments are also involved. The work consists of reforestation and construction of rough stone check-dams in deteriorated areas. The 3P-sampling procedure could be used to facilitate these works in the following ways:

(i) Estimation of nursery stock: The number of plants of different species in the nursery is mostly counted (100% count) at regular intervals for planning reforestation works in those areas due to be re-forestated. Assessment is simple, if stock has been raised in containers, but is time consuming, if raised in nursery beds, following hand or broadcast sowing when spacing is often uneven. The present counting procedure could be replaced by a simple 3P-sampling procedure. Each bed would have to be considered as a unit and plants in each would be estimated by eye. The estimates would then be corrected by an exact count in a small number of beds selected by 3P-sampling.

(ii) Assessment of regeneration: The extent of natural regeneration or survival, following artificial regeneration, has to be assessed for the purpose of evaluation. 3P-sampling could be used to speed up this work assuming the regeneration area could be broken into small units on a map, aerial photos or on the ground planting lines.

(iii) Measurement of check dams: Financial considerations make it essential to monitor the progress of construction work on check-dams so that targets are met. This involves measuring the volume of stonework already laid. This is a particularly cumbersome procedure as each dam is of a different size and the number of check-dam is generally substantial (e.g. in excess of 100). In such cases, 3P-sampling can provide alternative means of estimation at a much reduced cost and more quickly.

CHAPTER 7

CONCLUSIONS

Pakistan has only 3.7% of its land area under forest and only 1.5% under productive forests. This is totally inadequate to meet the national demand for wood. Consequently, wood and wood based products have to be imported. This drain on overseas funds can be reduced by improved management of the forests and, currently the Forests Departments of Pakistan are actively exploring ways to do this. One requisite will be complete statistics on the national forest resource at regular intervals. In the past it was impossible to provide such data but modern technological aid (e.g. computers, remote sensing imagery) and new advances in sampling theory and methods now make it possible.

3P-sampling introduced by Grosenbaugh (1964), used either alone or in combination with other variable probability or equal probability sampling procedures, appear to have definite potential for improving the efficiency of forest inventory in Pakistan.

Apart from this, studies in the U.S.A. indicate that the 3P-sampling can be used in wildlife and range management and for fuel hazard assessment. Undoubtedly, it will find application in many other situations which, as yet, are unexplored. Regardless of this, it is incumbent on the foresters of Pakistan to become thoroughly familiar with 3P-sampling and its many applications so that our inventory techniques will be cost-efficient and yield reliable data so necessary for more efficient management of our national forest resource.

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Appendix 1

3P SAMPLING MADE SIMPLE

By Harry V. Wiant, Jr.

The following explanation of 3P sampling is presented in easy-to-follow outline form.

1. Let us suppose we have a "forest" of 10 trees we wish to inventory using 3P sampling. Although unknown to us, the actual volumes of the 10 trees are:

Tree No.	Actual volume (board feet)
1	100
2	50
3	150
4	90
5	120
6	30
7	10
8	160
9	100
10	10
Total	820

2. To use 3P sampling we must determine the following:

(1) the number of 3P sample trees needed. This can be done statistically by calculating the coefficient of variation,

$$cv = \frac{\text{the standard deviation}}{\text{the mean}} * 100$$

of the ratios of measured to estimated volumes, which is usually about 20 percent. We assume it is 20 percent and wish to estimate the volume within 10 percent of the true value with one chance in three (67 percent level) of exceeding 10 percent.

$$n = \frac{t^2 c^2}{E^2}$$

where, n = number of 3P sample trees needed

t = approximately 1

C = coefficient of variation (20 percent)

E = allowable error (10 percent)

$$n = \frac{(1)^2 \quad (20)^2}{(10)^2} = 4$$

(2) Estimate the total volume, which we will assume is 1000 board feet.

(3) Estimate the total number of trees, which we will assume is 12.

(4) Estimate the volume of the largest tree, which we will assume is 150 board feet.

3. To select our 3P sample trees, we need a list of random numbers from 1 to 'KZ'.

(1) KZ = estimated total volume/desired number of 3P samples

= 1000/4 = 250

(This indicates we will select one 3P sample tree for about every 250 board feet of volume.)

(2) Using a table of random numbers, we select 12 numbers between 1 and 250. However, since the largest tree we expect to encounter will have 150 board feet, numbers above 150 are "nulls" and will be designated with a "-". (All trees found with estimated volumes greater than 150 board beet must be measured, termed "100 percent measured".)

(3) Trees whose estimated volume is equal to or greater than a paired random number are 3P sample trees.

4. The random numbers and our estimated volumes are as follows:

Random number		Tree number	Estimated volume
(153)	-	1	90
	52	2	40
(177)	-	3	200
	63	4	90
(248)	-	5	100
(167)	-	6	40
(204)	-	7	20
(160)	-	8	150
	82	9	90
	75	10	20
(226)	-		
(176)	-		

(1) You will note we generated more random numbers than were needed, which is no problem.

(2) Tree no. 3 must be measured as its estimated volume exceeds 150 board feet, and it is not part of our 3P estimate.

(3) 3P sample trees, those whose volume equals or exceeds their paired random number, are trees no. 4 and 9.

5. Our field sheet might appear as follows:

MEASURED VOLUME

Tree no.	3-P	100 percent (x)	Estimated volume	Meas/Est.
1			90	
2			40	
3		150		
4	90		90	1.000
5			100	
6			40	
7			20	
8			150	
9	100		90	1.1111
10			20	
		150	640	2.1111

(x) This tree's estimated volume exceeded 150, thus it had to be measured and its volume is kept separate.

6. The average of the measured/estimated ratios is obtained:

2.1111/2 = 1.0556

7. Our volume estimate is:

(1.0556) (640) + 150 = 676 + 150 = 826 bd.ft.

(close to the 820 "actual volume")

8. Were our sample larger, we'd now calculate the coefficient of variation (standard deviation for measured/estimated ratios divided by the average ratio, all this times 100, or $C = S/\bar{x}\ (100)$ and the sampling error as a percent ($C/\sqrt{n}$, where n = number of 3P samples).

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APPENDIX 2 Computer Generated List of Random Numbers for Point-3P-Sampling Exercise

COMPARTMENT 80 STROMLO PRACTICAL EXERCISE #2 MSC CLASS PAGE 6
L= 987654321, LIM= 10000, K= 33, KZ= 349

-99999	-99999	-99999	-99999	27	-99999	-99999	-99999	-99999	-99999
32	-99999	-99999	-99999	-99999	-99999	-99999	5	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	4	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	32	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	19	-99999	-99999
-99999	-99999	-99999	-99999	-99999	19	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	33	-99999
-99999	-99999	-99999	-99999	30	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	22	-99999	-99999	-99999
-99999	22	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	14	28	4	-99999	-99999	17	-99999	-99999	-99999
32	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
25	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	28	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	5	-99999
5	-99999	-99999	-99999	-99999	-99999	-99999	22	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	3
-99999	-99999	-99999	-99999	-99999	28	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	6	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	2	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
12	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	8
-99999	27	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	15	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	17	-99999	1	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	14	-99999
-99999	30	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
17	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	7	-99999	-99999	-99999	-99999	-99999	-99999	22	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	18	29	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	22	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999

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Appendix 3

'STX' Computer program output

for Point-3P sampling exercise

conducted in A.C.T. plantation forest

TABLE 1. Sums of KPI (predictions) by Stratum

COMPARTMENT 80 STROMLO PRACTICAL EXERCISE 2 M. SC. CLASS EX2 PAGE 2
JCS 10/04/80 1 349. 33. 319+123020

PRELIMINARY REPORT--COUNTS AND AGGREGATE PREDICTIONS

SUM OF PREDICTIONS BY STRATUM

PLOT OR POINT NUMBER	ALL	STRATUM 1
1	554.11	554.11
2	646.46	646.46
3	381.19	881.19
4	554.11	554.11
5	504.79	504.79
6	599.18	599.18
7	295.49	295.49
8	623.81	623.81
9	283.18	283.18
10	410.35	410.35
11	42.33	42.33
12	854.26	854.26
13	415.58	415.58
14	908.13	908.13
15	811.93	811.93
16	265.51	265.51
17	817.95	817.95
18	677.73	677.73
19	548.27	548.27
20	684.52	684.52
21	574.36	574.36
22	899.74	899.74
23	617.94	617.94
24	782.20	782.20
25	801.75	801.75
26	383.28	383.28
27	598.38	598.38
28	598.38	598.38
29	402.19	402.19
30	541.73	541.73
31	303.70	303.70
32	726.41	726.41
33	398.09	398.09
34	492.48	492.48
35	351.99	351.99
36	543.63	543.63
37	484.96	484.96
38	363.72	363.72
39	488.87	488.37
40	371.54	371.54

Table 2. Sampling statistics for first-stage sample.

```
COMPARTMENT 30 STROMLO   PRACTICAL EXERCISE 2  M. SC. CLASS        EX2    PAGE    4
JCS 10/04/80                                       1    349.    33         319+123020
          PRELIMINARY REPORT--COUNTS AND AGGREGATE PREDICTIONS
=================================================================================
```

STATISTICAL SUMMARY OF PLOT DATA

STRATUM	SUMS PREDICTIONS	SUMS PREDICTIONS**2	NUMBER OF PLOTS
1	31085.83	19013670.01	57
ALL	31085.83		57

STRATUM	MEAN	STANDARD DEVIATION	STANDARD ERROR	STANDARD ERROR %	COEFFICIENT OF VARIATION
1	545.37	192.053	25.44	4.66	35.22
ALL	545.37			4.66	35.22

TABLE 3 Example of Tree Data Compiled by STX Computer Programme

COMPARTMENT 30 STROMLO PRACTICAL EXERCISE 2 M. SC. CLASS EX2 PAGE 6
JCS 10/04/80 1 349. 33 319+123020

DETAILED LOG AND/OR TREE REPORT

TREE/ NO./	VOLUME CU.M.	SURFACE SQ.M.	LENGTH M.	DIB CM.	LOG/ CODE	RANGE M.	INSTRUMENT READINGS TGRADS	FGRADS	SINELV
	.022	1.214	7.0	.2	UU	37.8	53.6	53.7	.6790
	.057	1.803	4.6	10.6	TW	32.1	51.5	59.4	.5800
	.000	.000	.0	14.2		29.1	50.0	61.5	.4830
	.026	1.287	6.6	.1	UU	35.4	52.8	52.9	.6890
	.051	1.561	3.8	12.3	TW	31.6	51.3	60.4	.5625
	.015	.360	.7	13.7	XX	28.9	49.9	61.1	.4845
	.000	.000	.0	18.2		28.2	49.5	64.6	.4710
	.214	3.950	5.9	18.2	SW	28.2	49.5	64.6	.4710
	.201	3.126	3.9	24.7	SW	26.3	43.3	70.1	.2820
	.081	1.151	1.3	26.8	SW	25.2	47.5	72.2	.1410
	.090	1.166	1.2	29.2	SW	25.1	47.4	74.4	.0895
	.100	1.203	1.2	32.3	SW	24.9	47.3	77.4	.0415
	.117	1.302	1.2	34.3	SW	.0	.0	41.1	1.1500
	.000	.000	.0	37.8		.0	-99.9	46.7	1.1500
2 SUMS	.973	18.123	37.3	/ 40.6 = D.B.H.			FREQUENCY =		91.726

PREDICTION = 27 D.B.T. = 6.60 FORK * OPTIONS = 1210 UNSEEN MATERIAL
CLASS = RP VALUE STRATUM = 1 BASAL AREA = .1295
PLOT OR POINT NUMBER 3 GROWTH = 1.40

TREE/ NO./	VOLUME CU.M.	SURFACE SQ.M.	LENGTH M.	DIB CM.	LOG/ CODE	RANGE M.	TGRADS	FGRADS	SINELV
	.040	1.408	4.1	7.0	TW	33.5	.0	7.0	.0000
	.011	.273	.6	15.0	SW	31.3	.0	15.0	.0000
	.043	1.132	2.1	16.1	SW	31.0	51.0	62.5	.5190
	.082	1.616	2.5	17.8	SW	30.2	50.6	63.6	.4625
	.141	2.330	3.1	22.6	SW	28.5	49.7	67.1	.4003
	.309	4.444	5.1	25.6	SW	27.8	49.3	69.3	.2995
	.212	2.720	2.8	29.9	SW	26.9	48.7	72.8	.1205
	.163	1.865	1.7	32.5	SW	26.7	48.6	74.8	.0175
	.138	1.413	1.2	37.3	SW	.0	.0	41.2	1.7000
	.000	.000	.0	40.9		.0	-99.9	45.7	1.1500
5 SUMS	1.144	17.200	23.1	/ 40.9 = D.B.H.			FREQUENCY =		93.862

PREDICTION = 26 D.B.T. = 3.80 FORK OPTIONS = 1216 UNSEEN MATERIAL
CLASS = RP VALUE STRATUM = 1 BASAL AREA = .1314
PLOT OR POINT NUMBER 3 GROWTH = 1.90

TABLE 4 Summary Report for all Stratum

```
COMPARTMENT 30 STROMLO   PRACTICAL EXERCISE 2  M. SC. CLASS       EX2    PAGE  19
JCS 10/04/80                                     1     349.    33      319+123020
     SUMMARY REPORT--SURE-TO-BE MEASURED TREES PLUS EXPANDED 3P SAMPLES
=================================================================================
```

TOTALS ALL 1 STRATA**

SAMPLE VARIABLES	SURE-TO-BE MEASURED AGGREGATIONS	3P-EXPANDED SAMPLE ESTIMATES	TOTAL SAMPLE ESTIMATES PLUS SURE
TREES(FREQUENCY)	8.945	3560.818	3569.763
PREDICT.(EF KPI)	29.460	9886.911	9916.371
B.A.(SQ.M. O.B.)	1.23	393.28	394.51
LENGTH(M.)	215.55	78719.96	78935.51
SURFACE(SQ.M. I.B.)	143.10	51756.27	51899.38
VOLUME(CU.M. I.B.)	9.19	3102.93	3112.12
REL.VAL.PER MF.UNIT	1.00	1.00	1.00
GROSS MF.UNITS	9.2	3102.9	3112.1
ST.ERROR(PCT.)	-----	2.0	2.0
GROSS WTD.MF.UNITS	9.19	3102.93	3112.12
ST.ERROR(PCT.)	-----	2.0	2.0

COMPONENT ITEMS	(1=) NUMBER	(2*) NUMBER	(1,2) NUMBER
MEASURED TREES	1	28	29
MEASURED LOGS	6	227	233

```
MF.UNITS=  CUBIC METERS
 =(   .10000000+01)*(CU.M. )+(    .00000000    )*(SQ.M. )+(   .00000000    )*(M. )
=================================================================================
```

TABLE 5 Calculation of Board Foot Volumes by Interpolation and Scaling. Other units of measure may be substituted for International, Scribner & Doyle log scales.

COMPARTMENT 30 STROMLO PRACTICAL EXERCISE 2 M. SC. CLASS EX2 PAGE 20
JCS 10/04/80 1 349. 33 319+123020

BOARD FOOT LOG AND TREE REPORT
LOG LENGTH 5.0 TRIM ALLOWANCE .1 MINIMUM LENGTH 1.0 PRODUCT CODE SW

TREE NO.	LENGTH M.	SCALING LGTH. M.	DIB CM.	BOARD FOOT VOLUME INT. 1/4	SCRIBNER	DOYLE	VOLUME CU.M.
	4.3	4.2	18.2	24.8	19.3	8.8	.144
	5.1	5.0	23.0	53.4	43.8	26.3	.244
	5.1	5.0	26.6	74.2	63.4	43.2	.419
	.0	.0	37.8	.0	.0	.0	.000
2	14.5	14.2	40.6=DBH /	152.4	126.5	78.3	.807

PREDICTION = 27 D.B.T. = 6.60/ .0 .0 .0 .000
CLASS = RP VALUE STRATUM = 1 / 152.4 126.5 78.3 .807
PLOT OR POINT NUMBER = 3 FORM CLASS = .662 FREQUENCY = 91.726
BASAL AREA = .1295 PERCENT DEDUCTION = .00

TREE NO.	LENGTH M.	SCALING LGTH. M.	DIB CM.	INT. 1/4	SCRIBNER	DOYLE	VOLUME CU.M.
	3.7	3.6	15.0	12.1	8.6	2.7	.038
	5.1	5.0	19.8	37.5	28.8	14.7	.209
	5.1	5.0	26.0	70.2	59.7	39.9	.315
	5.1	5.0	30.4	99.5	87.5	65.3	.510
	.0	.0	40.9	.0	.0	.0	.000
5	19.0	18.6	40.9=DBH /	219.3	184.6	122.5	1.122

PREDICTION = 26 D.B.T. = 3.80/ .0 .0 .0 .000
CLASS = RP VALUE STRATUM = 1 / 219.3 184.6 122.5 1.122
PLOT OR POINT NUMBER = 3 FORM CLASS = .749 FREQUENCY = 93.862
BASAL AREA = .1314 PERCENT DEDUCTION = .00

TREE NO.	LENGTH M.	SCALING LGTH. M.	DIB CM.	INT. 1/4	SCRIBNER	DOYLE	VOLUME CU.M.
	1.9	1.8	22.1	14.9	14.5	8.4	.072
	5.1	5.0	22.5	50.8	41.4	24.4	.211
	5.1	5.0	23.8	57.4	47.5	29.4	.303
	.0	.0	31.3	.0	.0	.0	.000
8	12.1	11.8	34.5=DBH /	123.2	103.4	62.2	.586

PREDICTION = 24 D.B.T. = 5.50/ .0 .0 .0 .000
CLASS = RP VALUE STRATUM = 1 / 123.2 103.4 62.2 .586
PLOT OR POINT NUMBER = 3 FORM CLASS = .693 FREQUENCY = 142.909
BASAL AREA = .0935 PERCENT DEDUCTION = .00

TABLE 6 Summary of Tree Data by Class and Grade

COMPARTMENT SU STROMLO PRACTICAL EXERCISE 2 M. SC. CLASS EX2 PAGE 32
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GRADE-YIELD AND REALIZATION REPORT

CLAS GR	CU.M. VOLUME	SQ.M. SURFACE	LIN.M. LENGTH	LOG FREQ.	COUNT
RP PW	84.313	1872.041	3716.282	1871.755	8
RP SW	4635.568	39370.293	48980.437	17043.800	148
RP TW	361.572	9948.300	24190.189	3353.708	68
RP UU	4.436	229.437	1247.932	183.452	2
RP XX	25.932	478.686	800.652	576.769	7
TOTALS	5112.119	51899.343	78935.467	28029.524	233

TABLE 7 Summary of Tree Data by Class, Grade (SW) against 1cm. DBH Group

COMPARTMENT 80 STROMLO PRACTICAL EXERCISE 2 M. SC. CLASS EX2 PAGE 34
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GRADE-YIELD AND REALIZATION REPORT BY DBH GROUP
CLASS RP GRADE SW

DBH GROUP	VOLUME CU. M.	SURFACE SQ. M.	LENGTH M.	LOG FREQ.	COUNT
29	79.637	1574.918	2539.858	1098.225	5
31	167.525	2761.293	3695.913	1380.156	4
32	107.479	1979.137	2963.725	1166.886	6
35	162.171	2753.368	3815.776	1429.089	10
36	169.615	2616.364	3245.678	1149.151	4
38	98.166	1344.949	1477.787	655.856	6
39	466.172	6971.699	8669.171	2743.402	25
40	187.144	2711.977	3232.726	950.840	10
41	522.324	7411.955	8700.392	3278.302	33
42	325.532	4549.082	5274.831	1686.486	23
45	92.900	1277.061	1475.519	429.598	6
47	40.220	671.455	918.720	196.331	3
48	115.578	1512.833	1687.902	436.090	6
49	101.408	1234.822	1282.461	443.393	7
TOTAL	2635.869	39370.913	48980.456	17043.805	148

TABLE 8 Summary of Tree Data by Class, Grade (TW) against 1cm. DBH Group

COMPARTMENT 30 STROMLO PRACTICAL EXERCISE 2 M. SC. CLASS EX2 PAGE 35
JCS 10/04/80 1 349. 33 319+123020
GRADE-YIELD AND REALIZATION REPORT BY DBH GROUP
CLASS RP GRADE TW

DBH GROUP	VOLUME CU. M.	SURFACE SQ. M.	LENGTH M.	LOG FREQ.	COUNT
29	14.998	518.746	1490.414	439.290	2
31	36.670	990.029	2269.552	1035.117	3
32	12.046	402.170	1113.719	388.962	2
35	15.968	483.899	1303.245	714.545	5
36	31.132	936.438	2184.217	861.863	3
38	7.139	234.928	647.068	109.309	1
39	37.367	1111.577	2836.700	989.132	9
40	45.285	1326.939	3250.065	676.609	7
41	90.113	2367.861	5346.485	1713.001	17
42	9.081	321.342	944.207	556.583	6
45	3.083	107.369	310.695	71.600	1
47	54.190	1045.535	2069.656	588.992	9
48	2.038	55.675	175.902	145.363	2
49	2.463	35.795	248.269	63.342	1
TOTAL	361.572	9948.301	24190.192	8353.709	68

TABLE 9 Stand Table by Class based on all Trees Input on either One- or Two-Stage Sample

COMPARTMENT 30 STROMLO PRACTICAL EXERCISE 2 M. SC. CLASS EX2 PAGE 38
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NUMBER OF TREES BY DBH GROUP
CLASS RP

DBH GROUP	NUMBER OF TREES	BASAL AREA	PREDICTIONS	COUNT
16	69.38	1.31	1040.73	1
18	101.26	2.62	1412.04	2
22	32.29	1.23	355.21	1
23	31.51	1.31	504.16	1
25	153.39	7.52	3108.37	6
26	25.63	1.31	512.69	1
27	111.40	6.36	2291.07	5
28	162.53	9.98	3388.64	7
29	191.22	12.53	4417.37	10
30	126.69	8.89	3000.33	7
31	149.31	11.36	3480.93	8
32	206.87	16.51	4789.93	13
33	223.23	18.92	5415.57	15
34	221.44	20.01	5052.56	14
35	301.09	28.89	7114.20	21
36	324.56	32.93	7811.19	24
37	245.91	26.38	6041.43	20
38	90.03	10.14	2228.47	8
39	252.77	30.16	6307.62	24
40	221.01	27.67	5606.48	22
41	153.94	20.23	3884.40	16
42	136.39	19.00	3485.98	14
43	105.65	15.25	2641.01	12
44	157.82	23.88	4004.37	18
45	64.36	10.20	1674.78	7
46	53.81	8.87	1400.44	7
47	50.41	8.71	1316.89	7
48	56.10	10.16	1479.33	8
49	19.84	3.75	522.72	3
50	19.06	3.70	520.71	3
51	24.51	5.02	624.56	4
52	5.90	1.25	165.12	1
53	11.15	2.46	245.11	2
55	5.35	1.25	112.31	1
TOTAL	4106.36	409.75	95956.78	313